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COMING MEETINGS

Midwinter Convention, Philadelphia, Pa., February 4-8

Spring Convention, Birmingham, Alabama, April 7-11

Annual Convention, Evanston, Ill., June

MEETINGS OF OTHER SOCIETIES

American Society of Mechanical Engineers, New York, N. Y., December 3-6

Society of Naval Architects and Marine Engineers, New York, N. Y., November 8-9

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Special Features in the Design of Transmission Tower Lines as Imposed by Electrical Conditions

BY W. DREYER

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***Review of the Subject.**—This paper is confined to the factors which affect the structural and mechanical phases of transmission line design. These are divided into two groups as follows:*

1. Factors affecting design of tower.

2. Features involving location of towers.

The writer has in general refrained from commenting on the various items listed. Exceptions are made, however, in certain features which in his opinion deserve particular emphasis. Briefly, these are:

1. The consideration of an "economical stringing stress" as described under "Factors affecting Strength of Tower."

2. The description of transpositions.

3. Features involving location of towers.

Views and diagrams are used to describe the transpositions and a table giving data on the standard towers for the 110-kv. and 220-kv. transmission lines of the Pacific Gas and Electric Company is also included.

THE title assigned to this paper, namely "Special Features in the Design of Transmission Tower Lines as Imposed by Electrical Conditions," will, if strictly interpreted, cover a field somewhat broader than the scope of the writer's knowledge, which is confined strictly to the structural and mechanical side of the transmission problem. The paper will, therefore, be limited to those features which affect either the design of the supporting structures, or the location of these structures in the field.

The writer will attempt to enumerate all of the factors, giving a brief description of the more important points and describing how the problems are handled in the transmission lines of the Pacific Gas and Electric Company. The features of greatest interest,—transpositions,—are described by illustration. A table is also included which gives data on the standard towers for the 110-kv. and 220-kv. transmission lines of the company.

Factors Affecting Design of Tower

The factors which affect the design of the standard line towers may be divided into two groups, one affecting the shape and the other the strength of the supporting structure. These factors are briefly enumerated below:

(a) *Factors Affecting Shape of Tower:*

1. Type of tower—single vs. double circuit.
2. Permissible distance between phases.
3. Permissible distance between circuits.
4. Length and allowable transverse deflection of insulator string.
5. Sag of wire inside tower.

An allowance for sag inside of the tower based on a 20-deg. angle of pull will usually be sufficient for obtaining proper clearance between the wire and the members of the tower.

6. Minimum clearance between conductor and members of tower.

This clearance should be maintained, using a length from point of support equal to the length of the insulator plus the sag inside of the tower, this length being swung at the angle of maximum transverse deflection. This investigation will, particularly for single-circuit towers of the flat top type practically establish the shape of the transverse framing of the structure.

(b) *Factors Affecting Strength of Tower:*

1. Size and maximum stress of conductor.

The size of the wire on trunk transmission lines is usually selected to best suit electrical conditions. The maximum stress in the wire can, however, be controlled by the tension at which the wire is strung.

The usual practise in tower line construction is to string the conductor so that it will be stressed nearly to its elastic limit when under maximum loading. The writer believes that following this practise blindly will give neither the most economical nor the most satisfactory transmission line. Investigations have been made by our company to determine the conductor stress which would result in the lowest cost for supporting structures, consideration being given to both the towers and their foundations. This investigation showed that a maximum tension of 17,000 lb. per sq. inch for copper 250,000 cir. mil to 500,000 cir. mil in size resulted in the lowest cost of completed line. The use of this tension instead of 27,000 lb. per sq. in., resulted in a saving of about 20 per cent in the cost of towers and foundations. For the Pit River 220-kv. line this represents a saving of nearly $1200 per mile. In addition, this tension, which is only about 60 per cent of the elastic limit of medium drawn copper, greatly reduces the load on dead-end insulator strings, consequently reduces the number of dead-end insulator failures, and therefore gives a more satisfactory line.

2. Standard Span.

The standard span is determined by economic considerations and for steel towers on concrete foundations, greatest economy will result with spans 800 to 1200 ft. in length.

3. Type of Tower.

(a) *Double-Circuit vs. Single-Circuit.* It is customary to consider more broken wires for double-circuit than

Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Cal., October 2-5, 1923.

for single-circuit towers. It is our practise to assume three broken wires on standard double circuit towers, all wires being on one side of the tower. This case will usually occur when the top wire breaks and drops across the two lower wires. Two wires are assumed broken with standard single-circuit towers.

(b) *Standard, Anchor and Dead-End Towers.* Dead-end towers are designed to resist all wires broken at maximum stress in the conductor. This would occur under the condition of heaviest loading and with dead-end insulator strings.

For standard towers (designed for two or three wires broken) and for anchor towers (designed for all wires broken) no dead-end construction is permitted, the insulator string being suspended vertically. In this case when a wire breaks the insulator strings swing into the catenary, increase its length and therefore greatly reduce the tension in the span adjacent to the break. For our standard 110-kv. double-circuit lines the resultant stress is 78 per cent and for the 220-kv. double-circuit line, it is 66 per cent of the maximum conductor stress.

All towers of the Pacific Gas and Electric Company are tested to 50 per cent overload.

(c) *Transposition Structures.*

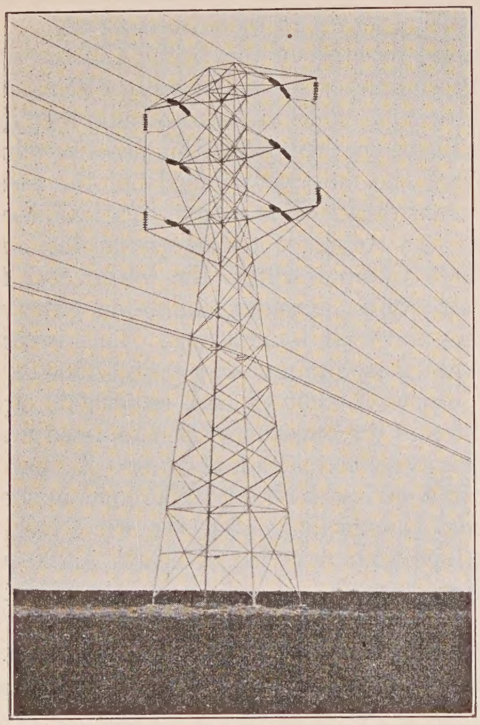


Fig. 1—110,000-Volt Transposition Tower

1. 110-*Kv. Transmission Lines.* Transpositions on the 110-kv. lines are of the conventional "Dead-end and jumper" type, where the transposing is done on a tower. Our standard 110-kv., double-circuit transposition tower is shown as Fig. 1. The only additions to the standard tower are extensions to the upper and lower arms.

2. 220-*Kv. Transmission Lines.* Transpositions on the 220-kv. Pit River line are of the "rolling type," that is, the wires are transposed without dead-ends or jumpers.

The double-circuit transposition structure, as shown in Fig. 2, consists of two standard line towers the cages of which are connected by two latticed bridges. A

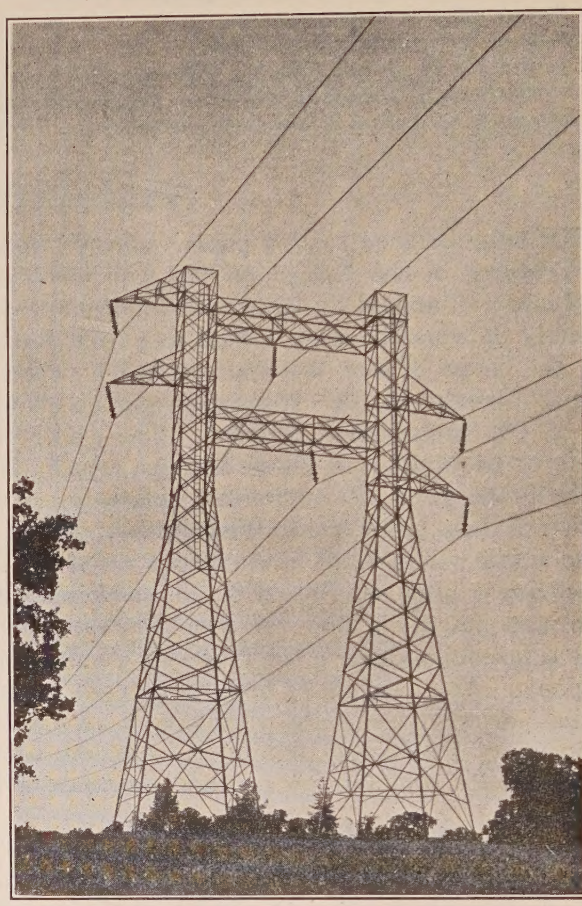
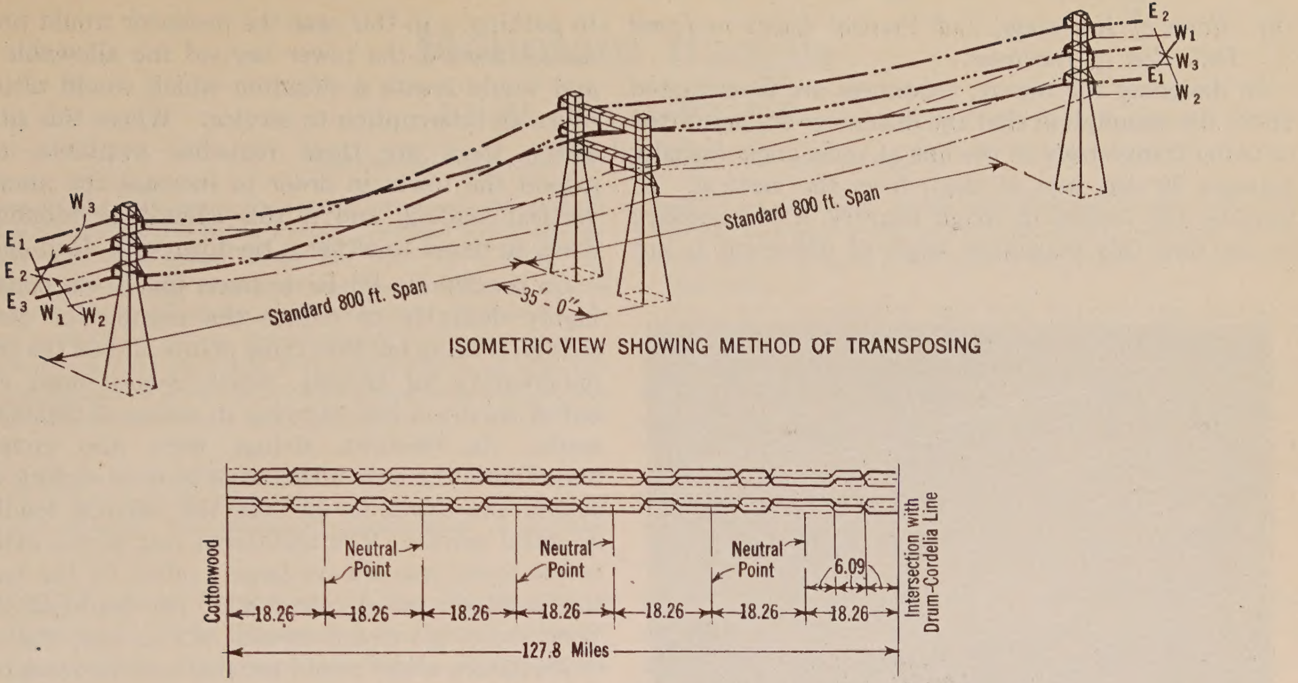


Fig. 2—220,000-Volt Double-Circuit Transposition Tower

diagrammatic plan showing the transposition scheme is shown on Fig. 3. It will be noted that the crossing wire of each circuit is pulled out of the vertical plane to an insulator suspended from the bridge, and that the transposition is completed in two spans.

The single-circuit transposition, shown diagrammatically on Fig. 4, requires three spans for completion. This was done to bring the crossing points of the wires on the towers rather than at the center of the span. The intermediate towers are standard line towers with an extension above them, and with a portion of the cross-arm removed. In order to reduce the side deflection of the insulators to a minimum, the intermediate towers are offset as shown on the plan. This results in the wires crossing in straight lines, with the insulators on the intermediate towers hanging vertically. Fig. 5 shows one of the completed transpositions; it will be noted that there is no deflection of the insulators except on the end towers, which is unavoidable.



LOCATION OF TRANSPOSITIONS

FIG. 3

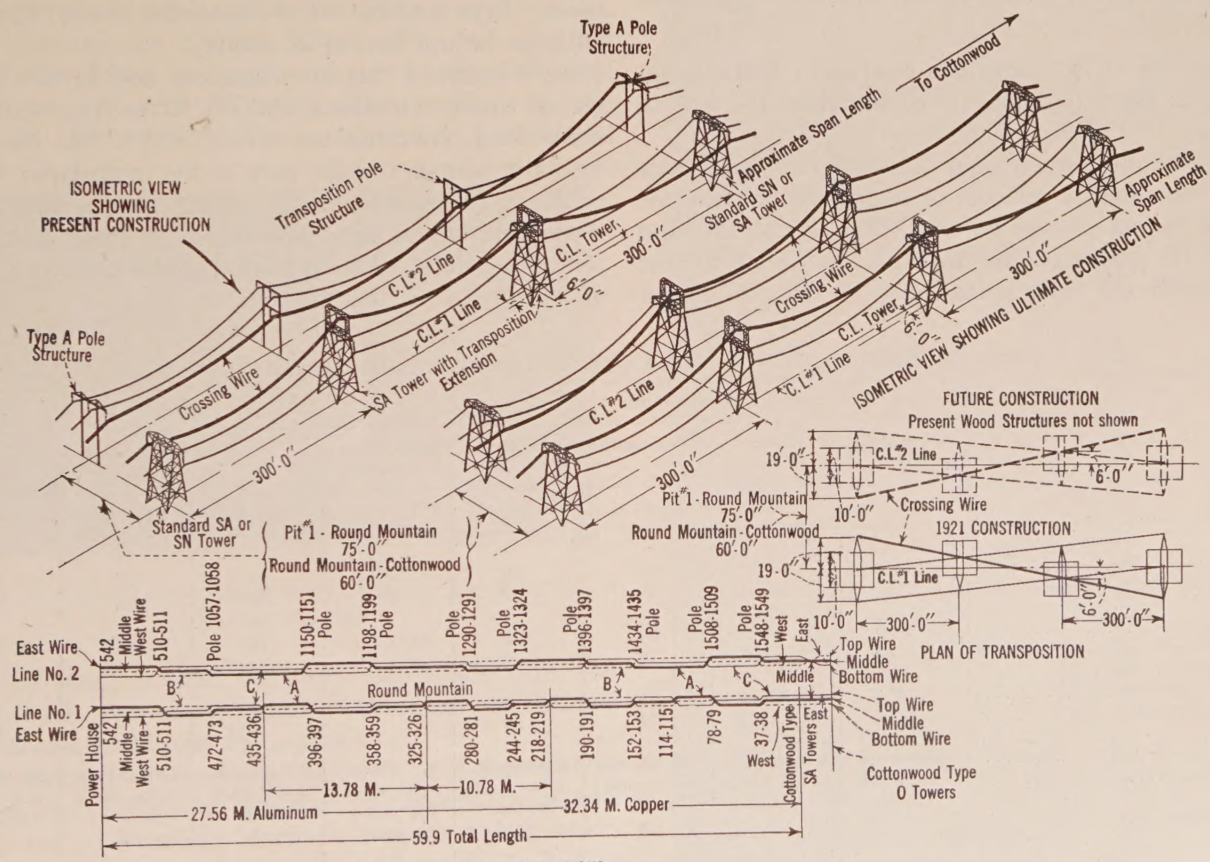


DIAGRAM SHOWING TRANSPOSITIONS

FIG. 4

FEATURES INVOLVING LOCATION OF TOWERS

(a) *Stagger or Offset of Towers on Twin Lines.*

Where twin tower lines traverse country that is not flat, it is impossible to set the structures directly opposite each other. The amount of offset that will be permitted should be based on maintaining a minimum clearance between adjacent wires equal to the distance between phases on the flat-top, single-circuit towers. The horizontal projection of the catenary as deflected by wind, furnishes the basis for the determination of allowable stagger.

(b) *Ratio of Horizontal and Vertical Loads to Limit Deflection of Insulator.*

In designing the towers, clearances are investigated under the assumption that the insulators are permitted to swing transversely to the line at some angle (usually between 30 deg. and 45 deg.) from the vertical. In locating the towers in rough country it is necessary to see that this maximum angle of deflection is not exceeded, for if it should be, clearances become impaired and there is danger of arcing from the line to the tower.

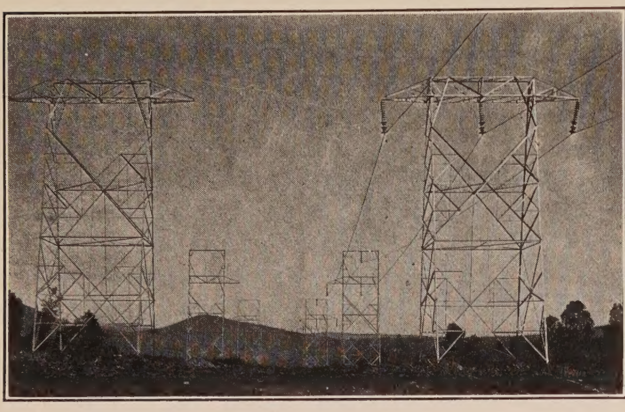


Fig. 5—220,000-Volt Single-Circuit Transposition Tower

A typical illustration of a doubtful location is one where one tower is placed in a depression with the adjacent towers on high ground. The horizontal wind load on the intermediate tower is unaffected by the profile, while the vertical load may be reduced almost to nothing. In this case the insulator would probably deflect toward the tower beyond the allowable angle, and would create a situation which would ultimately cause an interruption to service. Where this situation exists, there are three remedies available, one to extend the tower in order to increase the amount of vertical loading, and if this cannot be economically done, to resort to either a tie-down or a dead-end.

On the 220-kv. Pit River tower line it was considered highly desirable to reduce the number of dead-end strings, it being felt that these points offered the greatest opportunity for trouble, which would mean cutting out of service a line carrying in excess of 200,000 kilowatts. As tie-down strings were also considered undesirable the only alternative to dead-ending was to extend the tower to increase the vertical loading at doubtful points. The additional cost of the extension to the tower was always largely offset by the value of the insulators saved (about $110 per dead-end string). With the single-circuit towers of this line, the saving in insulators alone would provide over two tons of steel in the extension. At other points the elimination of dead-ends permitted the use of the standard line tower (Type SA) instead of the anchor tower (Type SC) with an actual saving of money.

As a result of this investigation, and by the liberal use of tower extensions, the Pit River line, some 200 miles long, contains one tower which has dead-end insulator strings to take care of the irregularity of the profile. There are only 21 points on the line where dead-end strings are required, 2 of these being the terminal points, 18 at horizontal angles and one because of the profile of the ground.

DATA ON STANDARD TOWERS OF PACIFIC GAS AND ELECTRIC COMPANY

Item	220-Kv. Tower Lines				110-Kv. Tower Lines			
	Single-Circuit Towers		Double-Circuit Towers		Single-Circuit Towers	Double-Circuit Towers		
	Type SA	Type SC	Type M	Type 0-98	Type S	Type AH	Type BH	Type CH
Height								
Overall	55½′	55½′	97′	98′	49½′	83′	83′	83′
To Lower Cross-Arm	51½′	51½′	62′	63′	48′	58′	58′	58′
Width								
At base	20′ x 20′	20′ x 20′	20′	20′	14′ x 14′	16′	16′	20′
At cross arm	4′ x 20′	4′ x 20′	6′	6′	2′ x 14′	4½′	4½′	4½′
Conductor Separation								
Between phases	19′	19′	15′	15′	13½′	10′	10′	10′
Between circuits	..	..	24′	24′	..	17½′	17½′	17½′
Conductor								
Max. size (copper)	500,000 cm.	500,000 cm.	500,000 cm.	500,000 cm.	3-0	250,000 cm.	250,000 cm.	250,000 cm.
Loading	8 lb. wind ½″ ice	8 lb. wind ½″ ice	8 lb. wind no ice	8 lb. wind no ice	6 lb. wind 1½″ snow	8 lb. wind no ice	8 lb. wind no ice	8 lb. wind no ice
No. broken	3	3	3	6	2	3	3	6
Span								
Normal	500	500	800	800	400	800	800	800
With angles	...	1000	...	800	...	...	800	800
Max. on tangents	750	1500	1000	1800	400	1000	2000	2500
Max. contributing weight	1500	2100	1050	1800	400	2000	2500	5600
Max Angle	None	22½°	None	22½°	None	None	15°	45°
Type of Conductor Support	Suspension	D. E. or Susp.	Susp.	D. E. or Susp.	D. E. or Susp.	Susp.	D. E. or Susp.	D. E. or Susp.
Weight of Tower	5100 lb.	7270 lb.	8440 lb.	12,950 lb.	4250 lb.	5080 lb.	6200 lb.	7590 lb.
Foundations								
Concrete (cu. yds)	6.28	11.8	7.8	15.2	11.2	6.72	8.72	12.9
Excavation (cu. yds)	18.1	60.4	25.5	84.5	32.5	22.4	31.2	44.4

Transmission Line Construction in Crossing Mountain Ranges

BY M. T. CRAWFORD

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Review of the Subject.—*In crossing mountain ranges with a recent transmission line in the Pacific Northwest severe climatic conditions were encountered. Snow lies from ten to thirty feet deep, wind attains high velocities and the temperature ranges between wide limits. A strongly built steel tower line successfully met these conditions. At one point however, a somewhat unusual formation of frozen fog was found to successively build up and drop off of wires and towers producing stresses greater than it would have been reasonable to design a line to withstand, and as a result failures occurred.*

Conditions in the extreme loading area are outlined and the assumption made that the most severe stresses were largely of an intermittent nature. The subsequent modifications in the construction are discussed, which were designed to more efficiently stress the materials under intermittent strains, providing an increased flexibility by the substitution of suspension for strain forms of wire support.

Where line construction fails from excessive dead loading a stronger design throughout is no doubt the proper remedy. If however this loading is only excessive in one span at a time it may be relieved by longitudinal flexibility. While not submitting the principle of the elimination of strain forms as universally applicable in transmission line construction, it is hoped that this paper will elicit a discussion from authorities on the subject that will define its range of application.

* * * * *

AMONG recent extensions of the Puget Sound Power and Light Company is a 120-mile 110-kv. transmission line from the White River generating station to Wenatchee. This line was built up the Green River valley, over the Cascade Range near Stampede Pass at about 4000 feet elevation, down through the Yakima River valley and over the Wenatchee Range at an elevation of nearly 6000 feet, and down into the Columbia River valley to the City of Wenatchee. The engineering features of

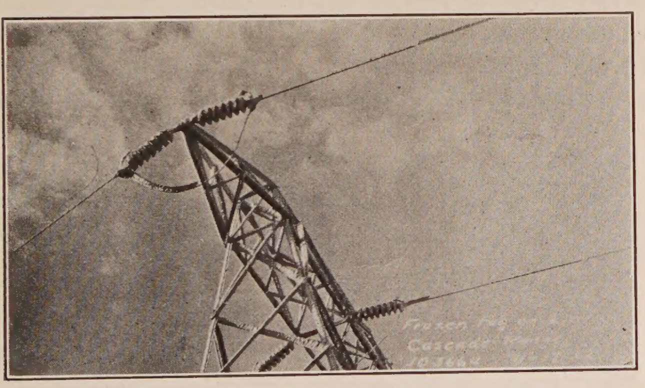


Fig. 1—Light Frost Formation Early in the Winter on Tower No. S25

this line were worked out with admirable care and skill, and the construction embodies exceptional mechanical sturdiness throughout.

On account of the heavy snows and inaccessibility of sections of the line over the two mountain ranges, additional mechanical strength was provided where the elevation exceeded 3000 feet. Type S. A. 55-foot steel towers were used for line supports, 4/0 B. & S. hard-drawn seven-strand copper cables for conductors, with O. B. No. 25620 cap and pin-type insulators, six-unit strings in suspension and seven-unit strings in strain. Spans were normally from 400 to 700 feet, with conductors pulled to a tension which would stress the wire to its elastic limit of 4250 lb. at 0 deg. fahr., 8 lb. wind pressure and one-half inch of ice coating.

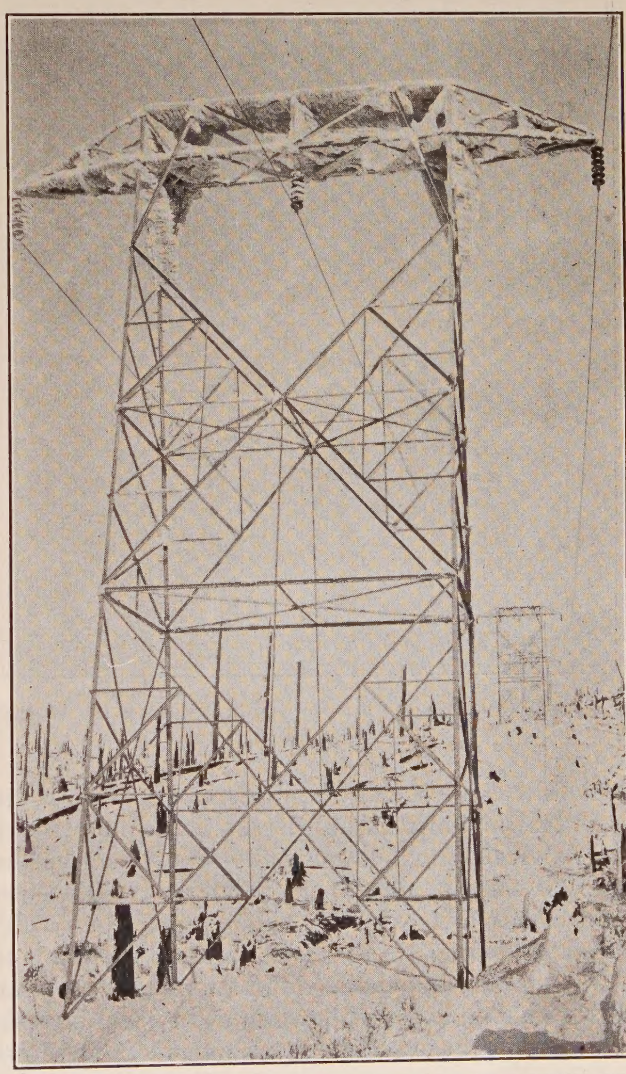


Fig. 2—Heavy Frozen Fog Formation Later in Winter, Tower No. S23

Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Cal., October 2-5, 1923.

Although the Wenatchee Range crossing was at a higher elevation, the climatic and topographic conditions over the Cascade Range were much more severe from the standpoint of line operation. The summit of this range marks a radical change in climatic conditions, from the moderate temperatures and damp winters of the Puget Sound area to the wider range in temperature and dry climate of Eastern Washington. In crossing the Cascade Range at Stampede Pass, it was necessary to locate the line at a bare exposed

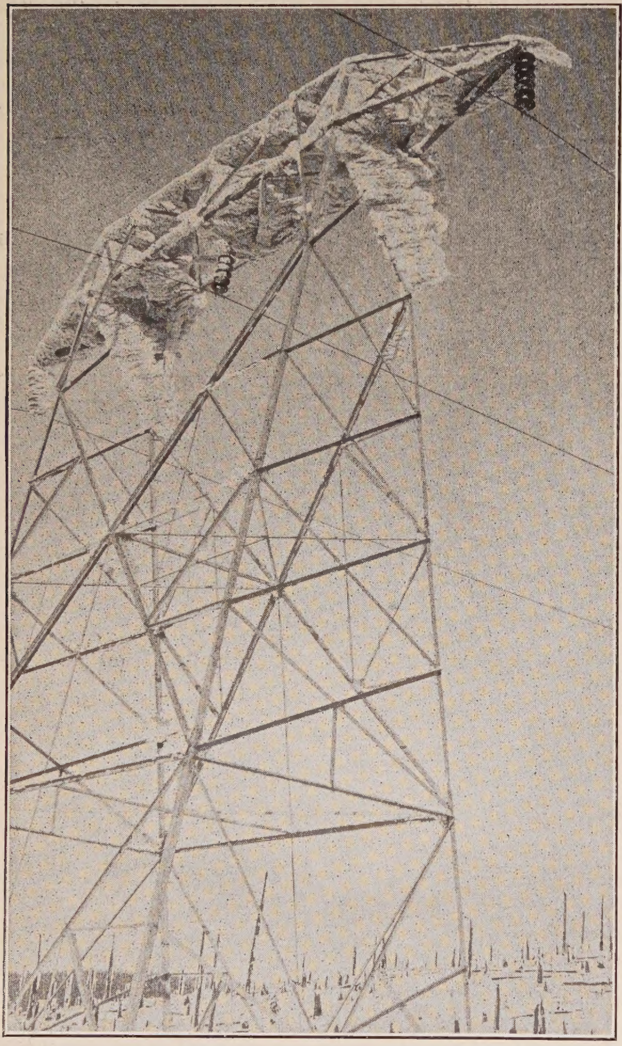


FIG. 3—HEAVY FROZEN FOG FORMATION LATER IN WINTER, TOWER NO. S23

point, where the summit was clearly defined. It was found that at times during the fall and winter months a heavy frost formation builds up on exposed surfaces near this summit, due to the wind carrying moisture-laden clouds of fog up from lower elevations, which freezes as it strikes the cold surfaces, building out rapidly toward the wind. Formations up to a maximum of about two feet in thickness in one direction were observed. As soon as the weight of the frosty mass becomes great enough it falls off and the building-up process starts again. The weight was estimated at from 5 to 10 lb. per cubic foot. Observations were taken from time to time during the first winter and advice sought from officials of the Weather Bureau. The indications were that the conditions bringing about this formation are apt to recur a number of times per year, but usually within a limited area, as the contact with cold air soon turns the fog clouds into snow. This formation has been found to occur

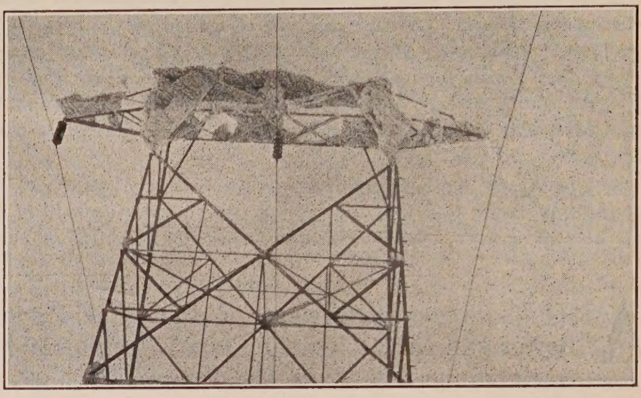


FIG. 4—HEAVY FROZEN FOG FORMATION LATER IN WINTER, TOWER NO. S26

along only about one mile of line near the summit, from observations made so far. The photographs were obtained after the atmosphere cleared and the formation had dropped off of the wires.

One break occured in the line during the first winter, which is considered too many for trunk line operation by an organization that has high standards of service. A careful study was therefore made of all the factors

FIG. 5—CLOSE-UP OF FORMATION ON TOWER NO. S26

involved in order to plan reinforcement work. As shown in the photographs and profile, the south wire was pulled in two in the second span east of the summit, but no insulator strings failed on this wire, although the wire slipped through the clamp at the next dead end east of the break. The other two wires were not broken, but three insulator strings pulled in two and one clamp slipped at the dead end points adjoining. It should be especially noted that there were several suspension towers in between these failures, but no

evidences of insulator damage or wire slipping were found at suspension points. Two of the insulator failures were of a character typical of the failure of cap and pin-type insulators under extreme tension, the porcelain parting well up under the cap with a fracture at right angles to the tensile stress. The third failure was in the lip of the cap casting. The wire failure was typical of a tensile break, six of the strands being drawn out to a reduced diameter before parting. The seventh strand had a brazed lap joint at this point which was put in at the time of manufacture and apparently parted somewhat more easily than the other strands. The effect of this was probably

Fig. 6—Line Damage, Tower No. S26, Looking Northeast Showing Broken Wire

to reduce the strength of the cable at this point a few per cent, which accounts for the wire parting and not the insulators on this conductor.

The towers were not damaged by the frost formation. Later in the winter heavy snow falls packed down to a depth of eight to ten feet, very hard on top. The spring melting underneath and the settling of this packed crust damaged the tower members badly in places near the ground and sheared off bolts.

The ultimate strength of this conductor is about 8500 lb. and of some of the insulator disks probably slightly less. Approximate computations indicate that a quiescent dead load on the wires in these spans would not have equalled this ultimate strength with the largest formation that evidence could be found of adhering to the wires. This formation builds out almost horizontally toward the wind from the con-

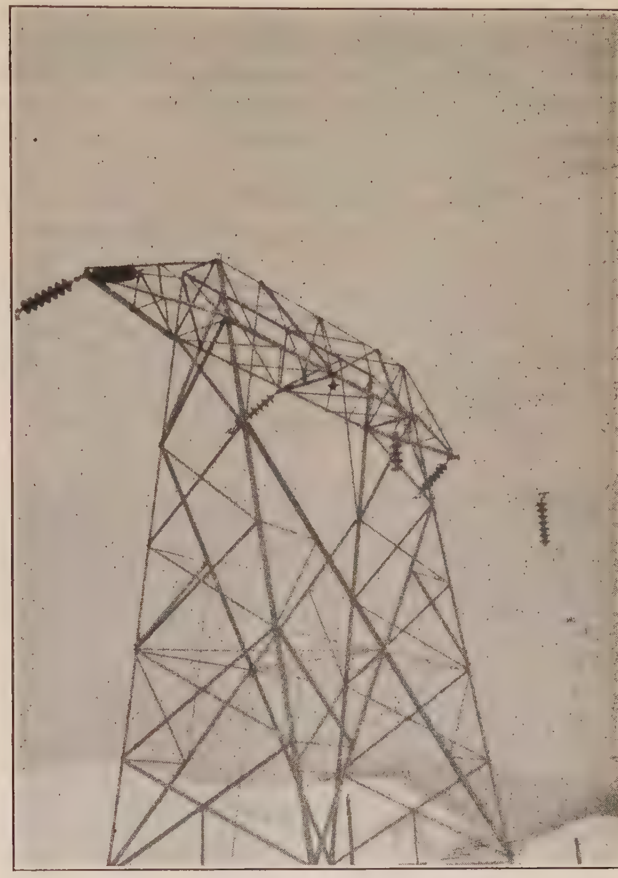


Fig. 7—Line Damage, Summit Angle, Tower No. S25, Looking North

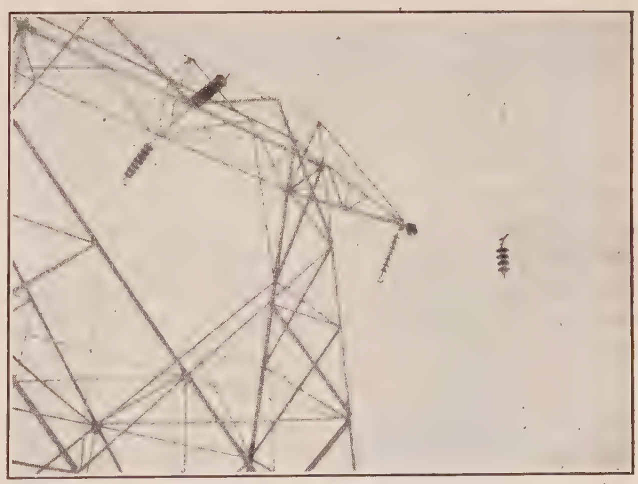


Fig. 8—Line Damage, Tower No. S22, Looking Northwest

ductor, forming in a narrow elliptical cross-section up to about 3 by 8 inches before dropping off, weighing possibly one and one-half to two pounds per lineal foot. It is believed that the building up and falling

off of the heavy frost formation on the conductors resulted in intermittent strains and jerks of a very severe character near dead end points which exceeded the strength of the wire; and that where the insulator strings failed or clamps slipped at dead end points, this tension was relieved thereby, but where the insulators held rigidly the conductor was broken. It should be noted that the damage along the two wires that stayed up through the winter was such as to virtually convert the construction to a suspension form through the loaded area.

In the heavily timbered Puget Sound region it has been found expedient to build some less important lines with only a narrow swath cut through the timber, the tall firs towering above the wires on each side. Branches and sometimes entire trees will often be blown across the line, producing a suddenly applied extreme loading. Many years of experience with this sort of trouble has shown that the most flexible types

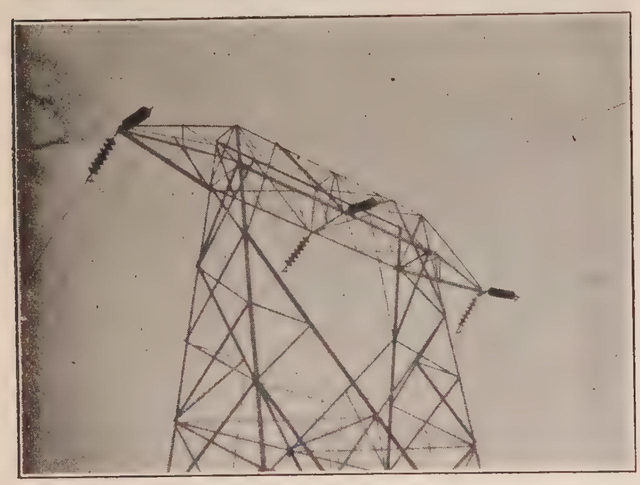


Fig. 9—Line Damage, Tower No. S21, Looking Northwest

of line construction are the least damaged. For example, one 110-kv. line of this class is built on a single wood pole line with light crossarms and suspension construction with few dead ends. Trees and branches will often fall on the wires without breaking them, although they may be carried to the ground. The tension is relieved by pulling slack out of spans some distance on each side, with possibly a few broken crossarms. On lines where wires are rigidly held the damage is much more severe.

Conclusions reached involved a redesign of certain features of the construction through the exceptional loading area, to provide:

1. A reduction in working tension on insulator strings which will safeguard against failure, as well as improve the electrical reliability.

2. A flexibility in wire supporting mechanism to allow some longitudinal movement of wires at all supports, which will permit the easing off of temporary over stresses from one span into adjoining spans.

3. Additional strength in tower members near the base.

It is believed that the substitution of the suspension form of support for all dead ends has taken care of the first two requirements. The insulator string under suspension conditions carries only the resultant of the

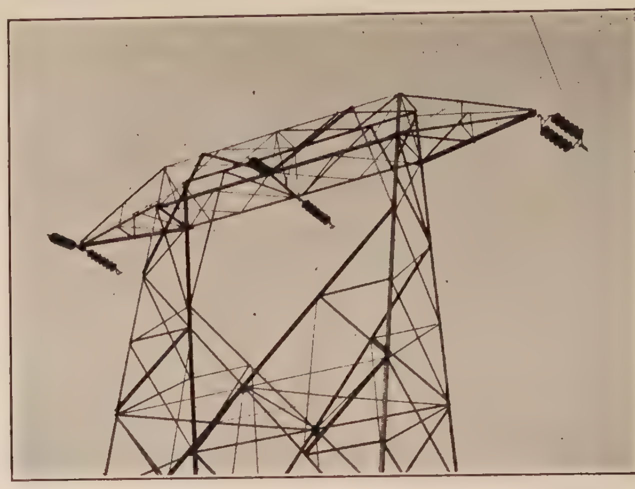


Fig. 10

Angle strain tower No. S25 at Summit, with one wire changed to suspension form of support and two yet to be changed. Wire was hung in free running sheaves for over a mile before placing in clamps to insure balanced stresses at supports.

respective wire stresses in each direction, and the dead end loading is largely shifted from porcelain to copper, reducing insulator tensions without increasing the number of insulators on the line. The suspension unit installed in places of former strain construction

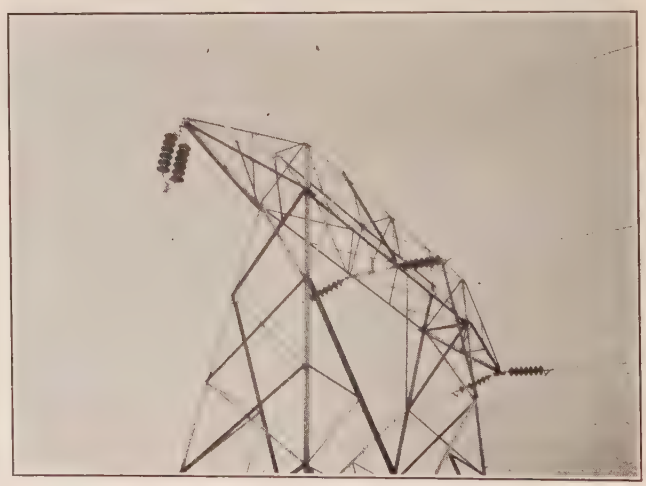


Fig. 11

Straight Strain Tower No. S22, with one wire changed to suspension form and two yet to be changed.

was made up of two strings of insulators in parallel with strain yokes at each end, which reduced the tension duty in the porcelain by half. This yoked double string unit was installed to hang approximately in vertical suspension, and the wire so pulled as to

give normally equal tensions on each side. At such times as abnormal loads come on one side these suspension units will swing out into the position of strain units. The necessary spacing out was provided at tower fastening and wire clamp to allow this with proper clearances.

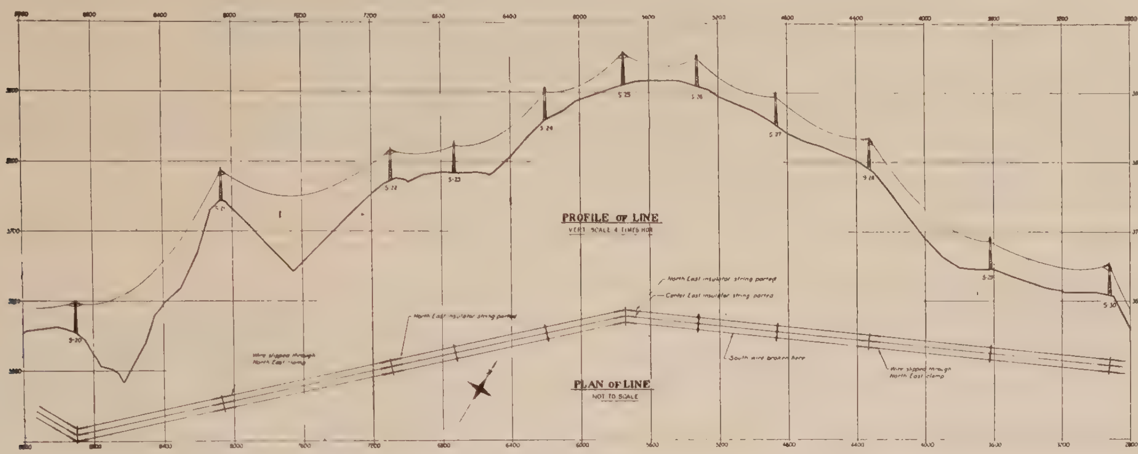


FIG. 12—TRANSMISSION LINE CROSSING CASCADE RANGE, NEAR STAMPEDE PASS
Showing details of damage by heavy frost formation.

Computations indicate that a slight increase in the length of arc resulting from this swinging out of suspension units makes a very material increase in sag and corresponding reduction in tension. Under extremely unbalanced conditions the conductor might even sag down until it touched the snow in the center of the span. This movement is restricted, however, by the amount of sag that can be pulled out of the several adjoining spans in each direction, and an equilibrium is usually reached after a slight movement which equalizes tensions. This action is very common on lines of suspension construction with wet snow alternately sticking and falling off of wire spans, resulting in short circuits where vertical wire arrangements are used.

In replacing strain forms with suspension forms on long steep slopes where it is desired to have wire stresses unequal on each side of towers, it would be necessary to install additional tie down strings on the up-hill side, offsetting the point of clamping the suspension and tie down strings to wire several feet. This provides for necessary clearances, and gives some longitudinal flexibility. Had there been any sharp line angles in this section, the flexible construction could have been provided by installing additional towers so as to make a round turn with short spans, the suspension strings swinging out nearly horizontal. This form of corner construction has been successfully used on suspension insulator lines along county roads and railroads where the right of way turns on a wide radius. It involves the use of bracket supports for inside insulator strings to obtain clearances.

The snow damage to tower leg members will be prevented by the installation of additional pieces of heavier angle stock alongside existing members, with the corner of the angle facing upwards to form a roof effect and provide a cutting edge to break the snow.

If still more severe winters are encountered in the future which this construction will not withstand, a stronger conductor with more insulator strings yoked in parallel and possibly additional towers may be needed, but the principles of mechanical design are submitted as obtaining the best balance in the stressing of materials under such extreme loading conditions.

TESTING OF PORCELAIN INSULATORS

During the testing of porcelain insulators with a "60-cycle flash-over apparatus," gases are liberated having an odor greatly resembling that of ozone. Since the two main constituents of normal air are nitrogen and oxygen, and high voltages (approximately 90,000 volts) are used during the tests, the conditions are favorable for the production of ozone or oxides of nitrogen, and perhaps both simultaneously.

In view of previous work which the Department of the Interior, through the Bureau of Mines, has done on oxides of nitrogen in connection with mine gases and problems in gas analysis, tests were recently made at the plant of an insulator manufacturing company to determine the kind and amount of gases liberated.

It was found that the gases liberated during the testing of insulators, using a 90,000 volt "flash-over" 60-cycle testing apparatus, are mainly ozone. Oxides of nitrogen were not found in quantities greater than 0.2 parts per million, the limit of accuracy of the method used. The ozone concentration of the gas samples taken directly above the racks during the tests varied from 2 to 10 parts per million. From the information available on the physiological effects of ozone, the amount found in these tests should cause no serious symptoms or after-effects.

Mechanical Electrical Construction of Modern Power Transmission Lines.—Insulators for High-Voltage Lines

BY C. B. CARLSON and W. R. BATTEY

Associate, A. I. E. E.

Both of the Southern California Edison Co.

Review of the Subject.—*The paper deals with the investigations for economics followed by the design assumptions based on the economical findings; the limitations required by electrical clearances; the testing of the structures; the design assumptions of the cable attachments; the unusual requirements of loading for attaching cable to structures; the extensions required by nature of country traversed; and the erection problems.*

* * * * *

IN handling the subject assigned, a complete description of the problems encountered in the design of the 220-kv. transmission line from the Laguna Bell Substation to Eagle Rock Substation of the Southern California Edison Co. will form the subject matter for this discussion.

The design was started following a request from a committee assigned to investigate the electrical features of a line of this voltage. The questionnaire outlined investigation on the use of the following five sizes of conductors:

605,000 circular mill steel reinforced aluminum cable
1,000,000 " " " " "
1,500,000 " " " " "

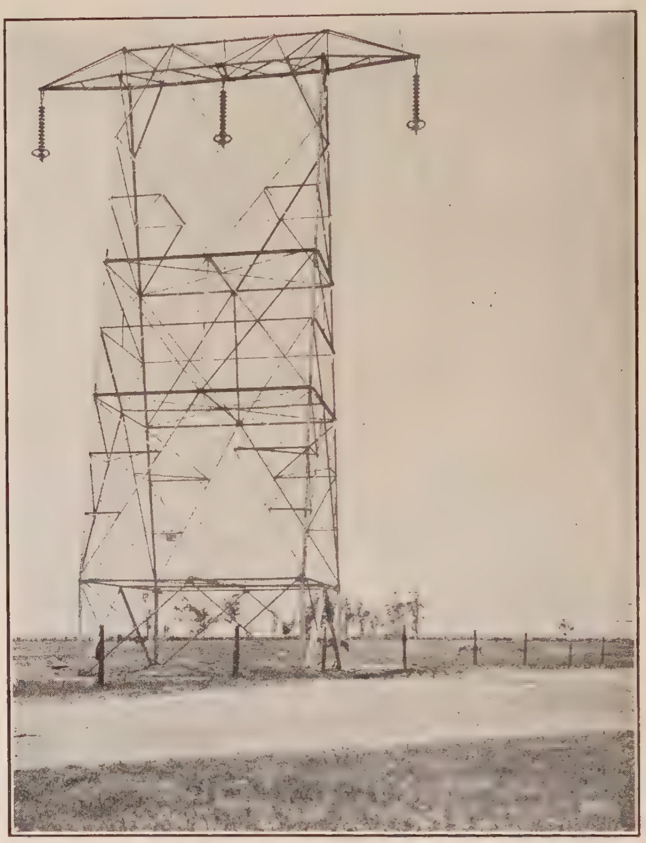
Copper cables of equal conductivity to the last two sizes.

There were several clearances to ground assigned for investigation together with a strict adherence to the recently adopted order of the Railroad Commission regulating high-voltage transmission lines.

FULL SIZE TOWER TEST

The first preliminary study eliminated from consideration the majority of the materials and limitations and further study was requested on the use of the following:

Cable—666,600-circular mill steel-reinforced aluminum, made up of 7 strands of extra high strength steel and 54 strands of aluminum having the following characteristics:



Diameter—1 inch
Ultimate tension—23,430 lb.
Elastic limit—16,180 lb.
Area—0.59 Square inches
Weight—0.86 lb. per lineal foot

Further, a single ground wire running over the top of the towers, was desired to provide the grounding for the line.

Having now fixed on the cable, a complete set of assumptions was made on which to base an economical study of height of tower and span.

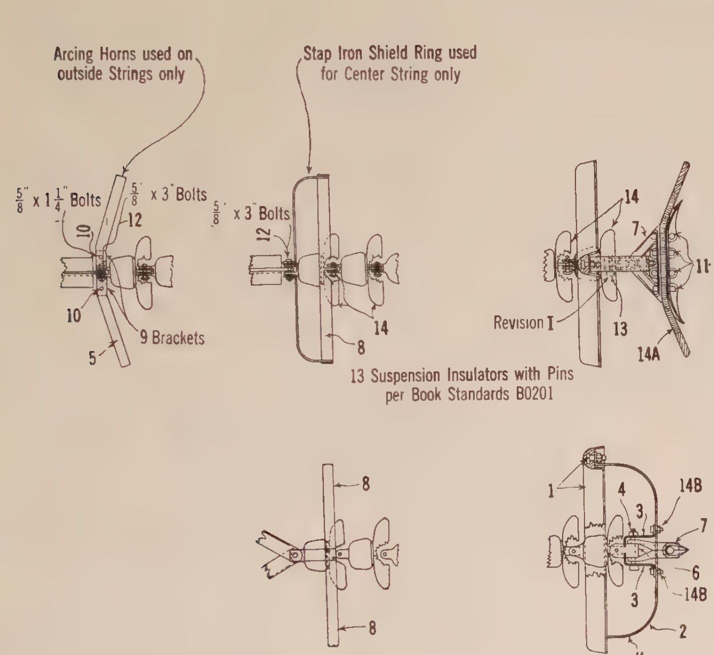
The calculations showed that with present-day costs and the assumed tensions that a span between 1150 and 1300 ft. would give the most economical line.

Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Cal., October 2-5, 1923.

Shortly before the need of ordering steel for the supporting structures, the Southern California Edison Co. needed a large quantity of steel for extending the heigth of the towers of their present 150,000-volt transmission line to meet the conditions of the new legislation regarding ground clearances. It was found that by considering the higher stresses permissible by the use of high-elastic-limit steel as manufactured by a Pacific Coast manufacturer that a saving could be made, so the towers for the 220-kv. lines were designed on the basis of this steel and other conditions of design which were as follows:

Span 1250 ft.
Tension in cable—12,000 lb. under maximum conditions
Electrical clearance to tower members—6 ft. under wind conditions
Insulators
Suspension—13—10-inch disks.
Dead-end double-string with 15 insulators in each
Shields—Aluminum castings supported on end of insulator strings and surrounding the bottom insulator.
Temperature range—10 deg. fahr.
Clearance to ground at minimum point—30 ft. at 120 deg. fahr.
Wind on Tower—10 lb. per square foot on 1½ area of one face
Wind on Line—8 lb. per square foot on projected area of wire
Footings—Earth with frustum of cone at 30 deg. for uplift resistance. Bearing according to soil.

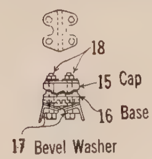
Full-sized tests were made at the steel company's testing frames as shown on accompanying photograph marked "Full Size Tower Test." The results of these tests, with the exception of a few minor details of connection, justified the design and were considered representative of the conditions of actual loading in the field under broken wire and maximum tension conditions with the required factor of safety. An illustration of the standard tower is included herewith showing the framing systems.



SUSPENSION INSULATOR STRING FOR STANDARD TOWER

Note:- Omit Item No. 8, Strap Insulator Shield Ring, when Arcing Horn Items No. 5-9-10 are to be used. For each Standard Tower use Item No. 8, Strap Shield Ring for Center Insulator String and Arcing Horns Items No. 5-9-10 for Outside Insulator Strings

LIST OF MATERIAL FOR ONE COMPLETELY ASSEMBLED GROUND WIRE CLAMP FOR STANDARD TOWER			
Item No.	No. Pcs Reg'd	Description	Detail Drwg. No
15	1	Ground Wire Clamp Cap	"29-Dr 30074-110
16	1	Do Do Base	"30 Do
17	4	Do Do Bevel Washer	"32 Do
18	4	5/8 ϕ Sq. Hd. Bolts 2 hex. nuts & Lock Washer	"17-Dr. 30074-132

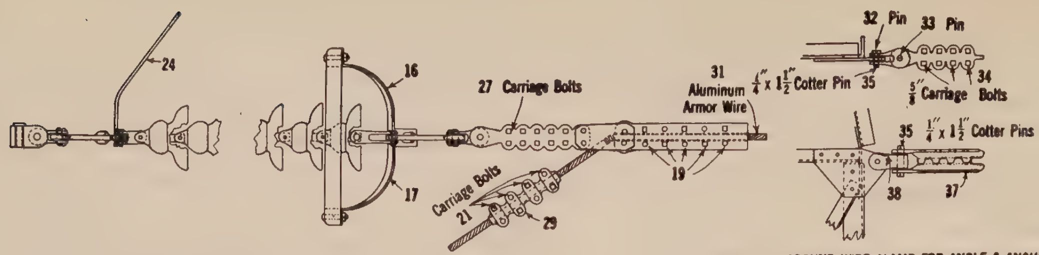


GROUND WIRE CLAMP FOR STANDARD TOWER

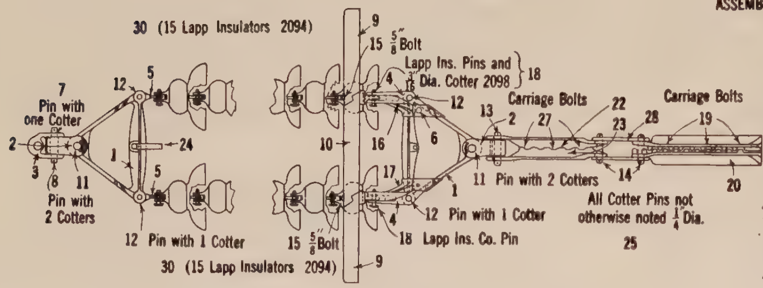
	LIST OF MATERIAL FOR ONE COMPLETELY ASSEMBLED SUSPENSION INSULATOR STRING FOR STANDARD TOWER			
	Item No.	No. Pcs Reg'd	Description	Detail Drwg. No
II	1	1	Suspension Shield Ring with Inset Bolts	#1-Dr. 30114 109-111
II	2	1	Supporting Arm for Shield Ring	# 2-Dr. 40001-347
II	3	2	Suspension Lugs	# 1-Dr. 40001-347
II	4	1	5/8" x 4 1/2" Bolt Hex. Nut & Washer	# 4-Dr. 40001-347
	5	1	Arcing Horn	# 6-Dr. 13015-215
	6	1	Suspension Clamp Clevis	# 38-Dr. 30074-132
	7	2	Suspension Clamp-Half	# 39-Dr. 30074-130
	8	1	Strap Insulator Shield Ring	#15-Dr 24133-428
	9	2	Arcing Horn Brackets	# 2-Dr. 13015-215
	10	2	5/8" x 1 1/4" Bolts- with Hex. Nuts & Lock Washer	
	11	8	5/8" x 3 1/4" Car. Bolts- 1 hex. nut & Lock Washer	#20-Dr. 30074-132
	12	1	5/8" x 0 3" Bolt Sq. Hd Hex. nut	
II	13	1.	Insulator Pin	El Stds B0201
	14	13	Suspension Insulators with Pins	El. Stds. B0201
	14A	1	14 Ft. length of .05 x .3 Alum. Armor Wire	
II	14B	2	5/8" x 1 1/2" Bolts Hex. nuts	# 3-Dr. 40001-347

Extensions were also then designed to meet conditions of country through which the line had to pass. These extensions were made vertical from the same footing spreads as the tower itself, thereby making the setting of stubs uniform throughout. Sidehill extensions both parallel and normal to the line were made, as considerable of the line traverses a mountainous country. Special footing extensions were made to take care of side slopes where sufficient resistance-to-uplift was not obtainable.

The committee having the features of the design of this line in hand required a factor of safety of 3 in the strength of the attachments of the cable to the towers. Due to limitations of clearances this required the hardware to be made of cast steel. The entire



ASSEMBLY OF GROUND WIRE CLAMP FOR ANGLE & ANCHOR TOWERS



ASSEMBLY OF DEAD END INSULATOR STRING FOR ANGLE & ANCHOR TOWER

LIST OF MATERIAL FOR ONE COMPLETELY ASSEMBLED GROUND WIRE CLAMP

Item No.	No. Pcs Req'd.	Description	Detail Drwg. No.
32	1	$\frac{7}{8}''$ Dia. Pin - Mach. Steel	No. 15 Dr. 30074-132
33	1	Do Do	No. 16 Do
34	8	$\frac{5}{8}''$ Carriage Bolts - 1 Hex. Nut - 1 Lock Washer	No. 23 Do
35	3	$\frac{1}{4} \times 1\frac{1}{2}$ Brass Cotter Pins	No. 25 Do
36	1	Ground Wire Half Clamp R. H.	No. 27 Dr. 30074-110
37	1	Do Do Do L. H.	No. 28 Do
38	1	Do Do Clamp Clevis	No. 31 Do

LIST OF MATERIAL FOR ONE COMPLETELY ASSEMBLED DEAD END STRING FOR ANCHOR & ANGLE TOWER

Item No.	No. Pcs Req'd.	Description	Detail Drwg. No
1	2	Dead End Yokes S. C.	No. 1 Dr. 30074-109
2	2	Yoke Attachment Clevis S. C.	No. 2 Do
3	1	Adapting Clevis for Vertical Pins S. C.	No 3 Do
4	2	Lower Insulator Clevis S. C.	No. 4 Do
5	2	Upper Do Do Do	No. 5 Do
6	2	$\frac{5}{8}'' \times 4$ Mach. Bolts - Hex. Nut & Cut Washer	No. 6 Dr. 30114-110
7	1	1" Dia. Pin drilled for 1 Cotter Mach. Steel	No 7 Dr. 30074-132
8	1	Do Do Do 2 Do Do	No 8 Do
9	2	Aluminum D. E. Shield Ring Part	No 1 Dr. 30114-110
10	2	Do Do Do	No 2 Do
11	2	1" Dia. Pin drilled for 2 Cotters Mach. Steel	No. 11 Dr. 30074-132
12	4	$\frac{3}{4}''$ Do Do 1 Do Do	No 12 Do
13	1	1" Do Do 2 Do Do	No. 13 Do
14	4	$\frac{3}{4}''$ Do Do 2 Do Do	No 14 Do
15	4	$\frac{5}{8}'' \times 3\frac{1}{2}''$ Carriage Bolts - Hex Nut & Cut Washer	No 5 Dr 30114-110
16	2	Supporting Arm for Double String Shield Ring	2R Dr. 30074-157
17	2	Do Do Do	2L Do
18	2	Lapp Insulator Pins # 2098	Dr. 40001-L 187
19	10	$\frac{5}{8}'' \times 2\frac{1}{2}''$ Carriage Bolts 1 Hex Nut & Lock Washer	No 19 Dr. 30074-132
20	2	Half Aluminum Cable Clamp S C	No 33 Dr 30074-131
21	8	$\frac{5}{8}'' \times 3\frac{1}{2}''$ Carriage Bolts - 1 Hex. Nut & Lock Washer	No 21 Dr. 30074-132
22	1	Core Clamp-Right hand half C. S.	No 34 Dr 30074-131
23	1	Do Left Do Do	No 35 Do
24	1	Arcing Horn Steel	No 24 Dr. 30074-132
25	22	$\frac{1}{4}'' \times 1\frac{1}{2}''$ Cotter Pins - Brass	No 25 Do
26	2	$\frac{3}{16}'' \times 1\frac{1}{4}''$ Do Do	No 26 Do
27	10	$\frac{5}{8}'' \times 4\frac{1}{4}''$ Carriage Bolts - 1 Hex Nut & Lock Washer	No. 23 Do
28	2	Splice Plates for D. E. Clamp	No. 36 Do
29	2	(Halves) Jumper Loop Splice Alum. Casting	No. 37 Do
30	30	Lapp Insulators 2094	Dr. 40001-L 187
31	1	20 Ft. length of 0.05 x 0.3 Alum Armor Wire	

requirements for hardware were designed and tested for loads three times the maximum tension.

A complete assembly of both the suspension and dead end strings is shown on plates marked "Assembly of Insulator String for Anchor Tower" and "Assembly of Insulators for Standard Tower." It is to be noted that to develop, on a factor of 3, the tension in the insulators that a special type of high-strength disks and pin connections was necessary.

The towers, except those in rather inaccessible places, which were assembled piece by piece, were erected by assembling the tower on the ground in two parts dividing the face normal to the line and bolting with loose bolts each leg to the footing studs. Then by means of two gin poles set aside the footings and a winch set on a truck and operated by its motor, the two halves were raised and connection made at the center gusset plates. The bridge of the tower was then hoisted in place.

The line stringing was also done by the use of the motor-operated winch and brought to tension by use of the sag method.

The unusual features in transmission line design such as the stringing tension, the spans, and the high voltages, made many difficult problems, but as the line is just now in process of erection, the complete justification for the assumptions cannot be completely told.

ELECTROLYSIS SURVEY AT GALVESTON, TEXAS

The final report of the Bureau of Standards covering its investigation of electrolysis conditions in Galveston has been completed and copies submitted to the utilities concerned. A somewhat unusual condition was found to exist in this city, although it is not unlike some other places located on low sandy ground close to the sea. A considerable part of the area of Galveston has been filled in with sand dredged from the Gulf, and, consequently, the resistivity of the soil is extremely low, ranging around 100 ohms per cu. cm. as compared with average figures of several thousand ohms commonly found in interior cities. Because of this extremely low soil resistance, some of the methods found effective in mitigating electrolysis in other cities were not adapted to conditions in Galveston. Some improvements in track conditions were carried out and further improvements recommended as a result of these tests.

Supplementary to this improvement in track conditions, the investigation showed that a properly designed and restricted pipe drainage system offered the best means of taking care of electrolysis conditions in Galveston. A pipe drainage system was already in existence, but it was found to be improperly installed and for this reason in many locations the drainage system itself was a source of danger to the pipes.

Group Operation of Systems Having Different Frequencies

BY E. R. STAUFFACHER and H. J. BRIGGS
Associate A. I. E. E. Associate A. I. E. E.
Both of the Southern California Edison Co.

Review of the Subject.—*The group operation of high-tension transmission systems having different frequencies has been successfully accomplished in Southern California during the past seven years. Some of the outstanding advantages of power interchange are emphasized and the value of the frequency changer for this purpose is shown.*

The metering of the interchanged power and the method of loading a frequency-changer offer somewhat unusual problems. With a liberal field design a synchronous frequency changer is of value as a means of power factor correction.

Certain troubles with the starting winding and the bearings of some of the machines have developed as a result of severe operating conditions but the frequency-changer has proved to be a reliable and satisfactory means of interchange of power between large systems.

GROUP operation of systems having different frequencies each of which is composed of a network of high-tension transmission lines has been successfully accomplished during the past seven years in Southern California. Frequency changers for this purpose have proved to be a reliable and rugged piece of equipment and have shown their value not only as a means of interchange of power, but also as a means of power factor correction when necessary.

The position of the Southern California Edison Company is unique in that it is, with one exception, entirely surrounded with systems operating at a different frequency. The above company interchanges power with the San Joaquin Light and Power Company (60 cycles) on the north; the Southern Sierras Power Company (60 cycles) on the east; and the San Diego Consolidated Gas and Electric Company (60 cycles) on the south. In addition to this there is an interchange of power between the systems of the City of Los Angeles and the Southern California Edison Company, but without the necessity of frequency changers as both systems operate at fifty cycles. To be more specific concerning the location and size of the various frequency changes, these data are given in the table "A".

The advantages of interchange of power between adjacent systems need not be gone into detail here. It is sufficient to summarize them as: (a) A means of disposing of large blocks of hydroelectric energy during off-peak hours which otherwise might be wasted; (b) a means of obtaining hydroelectric power and thus overcoming the necessity of generating power by means of the more expensive steam plants, with the further advantage that the steam plants can be held in reserve for emergencies; (c) when the hydroelectric systems concerned cover a wide area, as is the case in Southern California, a deficiency of snow-fall or of rain-fall, in one section is not serious when power can be obtained from a system where the power is obtained from a widely separated watershed; (d) three or more systems can attain greater operating economies when, by means of frequency changers and intermediate transmission networks, one system not directly connected with another can obtain power through the lines of the intermediate system; (e) a ready means of exchanging power in case of a breakdown of a major generating plant of any of the systems so inter-connected.

To give an idea of the value of group operation of a number of systems through frequency changers, table "B" has been prepared showing the amount of power interchanged during the past year.

FREQUENCY CHANGER AT CAPISTRANO SUBSTATION
5,000 kv-a., 50-60 cycles.

From a study of this table the flexibility of frequency changers as a means of interchanging power is well shown. In addition to delivering power from one company to another, the equipment can obviously be utilized as a means of delivering power to a third company.

It may be of interest to outline the method of metering when power is to be transmitted in either direction through a frequency changer. The scheme generally used is to have both sides of the machine equipped with a polyphase curve drawing wattmeter and two polyphase integrating watthour meters. Each of the integrating instruments is equipped with a ratchet mechanism so arranged that one instrument will meter energy only when power is flowing towards the frequency changer while the other will register only when power is flowing from the machine. By this combination the power delivered to either company is accurately recorded and the losses in the frequency

Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Cal., October 2-5, 1923.

TABLE A

Connection Between	Size of Unit	Voltage	Location of Unit
Southern California Edison Company (50 cycles) and Southern Sierras Power Company (60 cycles)	5,000 kw.—0.8 P. F.	11,000 volts (50 cycles) 6,600 volts (60 cycles)	Southern California's Edison Company's Colton Substation
Southern California Edison Company (50 cycles) and Southern Sierras Power Company (60 cycles)	5,000 kw.—0.8 P. F.	11,000 volts (50 cycles) 6,600 volts (60 cycles)	Southern Sierras Power Company's San Bernardino Steam Plant
Southern California Edison Company (50 cycles) San Diego Consolidated Gas & Electric Company (60 cycles)	5,000 kw.—0.8 P. F.	11,000 volts (50 cycles) 6,600 volts (60 cycles)	Southern California Edison Company's Capistrano Substation
Southern California Edison Company (50 cycles) and San Joaquin Light and Power Company (60 cycles)	15,000 kw.—0.8 P. F.	15,000 volts (50 cycles) 18,000 volts (60 cycles)	Southern California Edison Company's Vestal Substation

TABLE B

POWER INTERCHANGE (KW-HR.) THROUGH FREQUENCY CHANGERS

Month	Purchased and Delivered by Company "B' to Company "A"		Delivered by Company "C" to Company "A"	Purchased by Company "D" from Company "A"
	Substation No. 1	Substation No. 2		
January	100	1,850	0*	571,300
February	0	0	4,492,800	1,070,700
March	0	127,150†	604,800	1,799,850
April	0	0	99,000	3,184,300
May	8,150	1,350*	0	2,798,200
June	1,750*	0	41,400	2,767,200
July	342,500‡	1,462,850	19,800	1,957,500
August	24,700‡	211,050‡	5,079,600	2,192,900
September		19,750	7,619,400	1,910,700
October		450	8,499,100	1,749,300
November		300	6,080,400	1,558,700
December	120,050	137,550	5,337,000	1,400,800

*Purchased by Company "A'.
†Received for transfer to Company "D".
‡Part received for transfer to Company "D" and part utilized by Company "A".

changer throughout the month are definitely determined. The losses in the machine can, of course, be borne by either of the parties according to the terms of the contract, but the method usually followed is to bill the receiving company for one-half of the losses. Since the installation of the original frequency changer set in Southern California this method of metering has been used with satisfaction to all parties concerned.

The method of loading up a frequency changer has apparently not always been thoroughly understood. There has been some question as to whether the operator at the substation where the machine is located had control over loading, whether either of the systems concerned had to lower or raise their system voltage or if any adjustment in the frequency was necessary. After a frequency changer is in operation and synchronized with both systems and it is desired to load up the machine the system which is to supply the energy calls on its governing plant to pick up load. This plant opens the nozzles or wicket gates of the generator which is governing or "taking the swings" as it is termed, and in doing so the generator attempts to speed up the system to which it is connected and in doing so it picks up more load. The frequency changer in turn tends to speed up and in so doing it picks up load from the receiving system, or in other words, delivers power from the system which contained the governing plant. Due to the increase in current at the generating plant and at the frequency changer substation some slight adjustment of the voltage is necessary either by manual or by automatic means but this is a comparatively minor operation in picking up load.

The motor end of a frequency changer can, in addition to driving the generator end, be utilized for power factor correction. The adaptability of a synchronous motor for this purpose is well known, which feature is quite valuable on systems having a larger induction motor load and a network of comparatively long high-tension transmission lines. If it is contemplated using either end of a frequency changer set for power factor correction, care should be taken to specify a liberal design of the field winding. There have been a number of instances where the usefulness of a frequency changer for power factor correction has been limited because the field winding was not designed for a great amount of over-excitation.

Some of the major considerations to be made when the installation of a frequency changer is contemplated are:

(a) What will be its size in relation to the generating capacities of the two systems concerned, and will the set be required to furnish energy in either direction?

(b) What will be its location in regard to the principal generating plants of both systems?

(c) Voltage and frequency of each system?

(d) Rating of each unit? The specification for one of the frequency changers listed elsewhere in this paper calls for the following:

"Each unit will have a maximum continuous capacity when operating as a generator of 5000 kw., 0.8 power factor or 6250 kv-a. with a 50 per cent maximum momentary overload. When operating as a synchronous motor, each unit will be required to operate at 0.8 power factor leading, corresponding output

of the set being 5000 kw., 0.8 power factor. The temperature rise corresponding to the above conditions shall not exceed 50 degrees centigrade on either unit."

(e) Method of excitation, whether provided with individual exciters direct-connected, or if excitation will be provided from a motor-generator set or both, and whether an automatic voltage regulator such as a Tirrill is to be provided.

(f) *Efficiency.* If the set is to be operated continuously, the losses should be capitalized. For this reason the efficiency of the set for ¼, ½, ¾ and full loads should be specified, both for unity and some certain power factor leading for the motor and for unity and some lagging for the generator.

Frequency Changer at Vestal Substation
15,000 kv-a., 15,000 volts, 50-60 cycles.

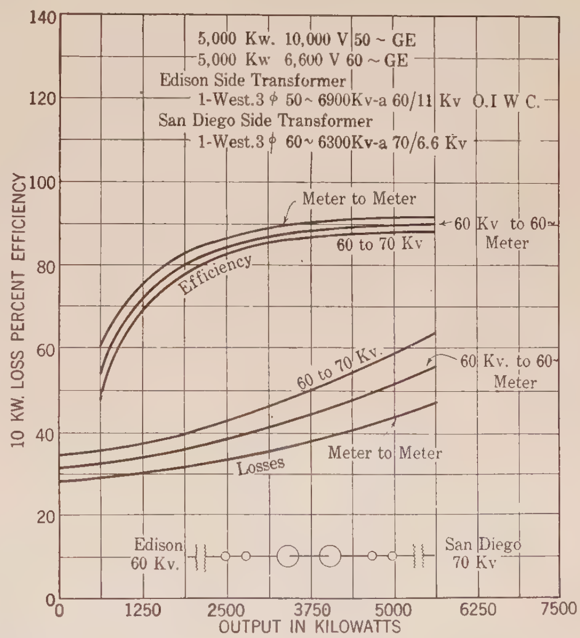
(g) *Starting Device.* Shall the set be capable of starting from either end and how will the starting be accomplished?

The experience of the Southern California Edison Company with frequency changers has been quite satisfactory during its seven years experience with such apparatus. There have been minor troubles, however, the chief of which have centered around the starting bars on the squirrel-cage winding and with the bearings.

After the first 5000-kv-a. machine had been in operation for about four years under conditions of rather severe service, it was necessary to take the machine out of service for approximately one month for the purpose of straightening the shaft. There has also been trouble with the motor bars coming loose. The original bars were replaced with bars of Monel metal. This change resulted in a different performance of the frequency changer on starting, in that the starting torque was much greater and the starting current was less, but there was more difficulty in falling into step than had been the case with the original bars.

It has also been an open question whether the trouble with the starting bars and the end rings of the frequency changer was due to the fault of the manufacturer or the result of the treatment of the machine. It must be realized that the excessive number of times of starting and stopping such a set as this will entail heavy duty on the squirrel-cage winding with the constant result of heating and expansion which will cause trouble later.

The largest machine on the system of the Southern California Edison Company (15,000 kv-a.) is a four-bearing machine and is equipped to use oil pressure in the bearings at the time of starting. Originally this machine was lined up so nicely that after the oil pressure had been applied it was possible for one man to move the rotor by applying his weight. There has been some trouble with the bearings, however, due to the fact that the conduits used for the bearing thermostat wiring accidentally short-circuited the insulating pad in the end bearings. After the bearing trouble occurred the conduit was removed and examined and evidence was found of considerable current flowing. This current flow was the result of accidentally short-circuiting the insulating pad which completed the circuit for the flow of circulating currents in the frame and shaft of the machine. The conduit was pitted and practically welded to the frame and base of the machine. There was evidence of pitting in the bearing and without doubt the circulating current



Efficiency Curves of Frequency Changer Set at Capistrano

was the cause of the bearing failure. Needless to say precaution has been used to eliminate the recurrence of such trouble by the same cause.

In regard to the protection of the frequency changer, time limit overload relays have been used on both ends so that in case of trouble on either system the frequency changer is disconnected on the side of the system in trouble. Power directional relays can be used to good advantage for this purpose. In addition to this it is necessary to provide some means of protection against

internal trouble of the frequency changer and this has been provided for at Vestal by means of two sets of power directional relays so wired that their contacts are closed when power is going towards the frequency changer. In addition to this the contacts on each set of relays are wired in series, so arranged that the tripping circuit will kick out the switches on both sides of the frequency changer. Under these conditions it can be seen that power will flow towards the frequency changer from both sides in case of a severe ground developing in the machine, and it is hoped that by this means to keep the damage to the machine windings and laminations down to a minimum.

In conclusion it may be stated that the frequency changer has proved to be a very satisfactory means of interchange of power, and that it should cause no trouble provided it is of the proper size in relation to the two systems which it connects.

Recent Hydroelectric Developments of Southern California Edison Company

BY H. L. DOOLITTLE
Southern California Edison Co., Los Angeles, Calif.

THE important water power plants constructed by the Southern California Edison Company in the last two years are Kern River No. 3, Big Creek No. 8, additional high-head impulse units in Big Creek plants Nos. 1 and 2, and the new Big Creek No. 3 plant which will be placed in operation the latter part of this summer. This paper will review some of the outstanding features of interest that have been incorporated in this work.

The Kern River No. 3 Plant

In this plant are installed two 22,500-horse power vertical turbines operating under head of 800 feet. To date these are the highest head reaction turbines that have been constructed, although a contract is now under way for another company for similar units to operate under total head of 850 feet. A recent inspection of the Kern River No. 3 runners showed them to be in good condition after nearly two years of operation.

One novel feature of these units is that they were designed to operate at a frequency of either 50 or 60 cycles, this being due to the fact that the load to be supplied by this plant is in 60-cycle territory part of the year and in 50-cycle territory for the remainder. Every precaution was taken to make the changing of runners as easy as possible and a design was finally adopted which accomplished this result very satisfactorily. Acceptance tests of the equipment show that an efficiency of 90 per cent was obtained and that the 50-cycle runner gave practically the same efficiency when operating at either normal speed of 500 rev. per min. or the 60-cycle speed of 600 rev. per min. There was, however, a somewhat lower maximum output when operating at the higher speed. The 60-cycle runner showed the same efficiency at normal speed but was considerably less efficient at the 50-cycle speed.

While the good condition of the runners after this long period of operation is mainly due to proper design it is also partly due to the absence of sand and silt in the water. Realizing that sediment of any kind would be very undesirable with these high head turbines an elaborate sand box was constructed for precipitating all foreign matter from the water. This sand box is 80 feet wide and about 500 feet long, reducing the velocity to about one-half foot per second. After several months of operation the sand box was inspected and it was found that about six inches of fine silt had been precipitated in the lower half of the box. This silt was so fine that forty-five per cent of it would pass a 150-mesh screen.

Big Creek No. 3 Power Plant

The Big Creek No. 3 power plant which is now under construction will consist at present of three 35,000-horse power turbines operating under a head of 740 feet. There is nothing unusual about the design of the main units, although several special features have been worked into other parts of the plant.

At the intake to the tunnel for this plant a cylindrical gate 22 feet in diameter and 90 feet high has been installed for shutting off the water to the tunnel line. This gate is motor-operated and is installed in a concrete tower located two or three hundred feet up stream from the dam.

A surge chamber is being constructed at the lower end of the tunnel. This surge chamber is excavated from solid rock and has an hour glass section, the bottom diameter being 60 feet, the central shaft 25 feet and the top diameter 75 feet. This hour glass section was adopted on account of the wide variation in water level at the intake under normal operating conditions. The large section at the bottom provides for a load suddenly applied and the large section at the top will take care of any surge created by loads rejected.

Connecting to the outlet of the tunnel is an 18-foot steel pipe which terminates in a manifold providing connections for six 7-foot, 6-inch diameter penstocks. The design of this manifold, which will operate under a total head of approximately two hundred feet, offered many difficulties. After much study a design

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was finally developed which consists of two plate steel spheres joined by a short section of pipe. To one of these spheres the 18-foot pipe and two of the penstocks connect, the other sphere providing connections for four penstocks. The adoption of this type of manifold permits taking care of the excessive stresses in a very simple manner and has successfully solved a rather difficult problem.

Several novel features have been incorporated in the penstocks for this power plant. The entire pipe lines will be of forge welded steel. As the pipes are to be installed above ground, expansion joints are used between anchors. These expansion joints are made so that the portion of the pipe on which the packing bears is copper-plated to a thickness of about 1/16 of an inch. This will provide a perfectly smooth and non-rusting surface for the packing and it is expected that all future trouble due to leakage will be eliminated. In a pipe line of this sort the friction on the supporting piers make necessary extremely heavy anchors at the bends. In order to reduce the size of the anchors to relieve the pipe of excessive longitudinal stress and also to facilitate erection, these pipes will be installed on cast iron rockers. Tests have shown that the friction will be reduced so greatly that a very large saving can be made in the cost of anchors and supporting piers. These rockers will be installed every 40 feet instead of every 20 feet as has been the custom heretofore with ordinary concrete piers.

In the power plant one of the important improvements that has been adopted is the elimination of an exterior lubricating oil system consisting of filters, supply tanks, pumps, piping, etc. It is felt that much more reliable operation will be obtained by simplifying the lubricating oil system to the greatest extent. The bearing on the water wheel and the generator bearings will be provided with gear-driven oil pumps which will pump the lubricating oil from a small sump below the bearings to the top of the bearings and thus keep it circulating continuously. Motor-driven pumps will also be installed, arranged to be started automatically in case the gear-driven pumps should cease to operate.

In the general arrangement of the station it is felt that a great improvement has been made, from an operating standpoint, by the elimination of the basement. The main floor of the generator room will be on two levels; about half of the generator room will have a floor on a level with the generator base and the other half will be on a level with the turbine. This will permit the maximum amount of equipment to be in view of the operators at all times.

Venturi Meters

It is now this company's practise to install Venturi meters in all new hydraulic plants. The Kern River No. 3 plant was equipped with Venturi meters at the time the plant was constructed. Venturi meters will be installed on the three units for the Big Creek No. 3 plant and similar meters have already been purchased for the six units in the Big Creek No. 1 and Big Creek No. 2 power plants. The importance and value of a reliable meter for measuring the water supplied to a water wheel has been proved in many ways. At Kern River No. 3 the Venturi meters are constantly used by the operators in their effort to obtain the maximum kilowatt hours output from the water available. Some recent tests on one of the Big Creek impulse units showed that the difference in output between a new and a somewhat worn nozzle was in the neighborhood of $1,000.00 per month. As this amount is several times the cost of installing new nozzles it emphasizes the value of having a continuous check on the efficiency of the wheels.

Draft Tubes

The Kern River No. 3 turbines are equipped with the regular quarter bend draft tube. The turbine in the Big Creek No. 8 plant has a spreading type of draft tube while the new turbines for the Big Creek No. 3 plant will have a modified spreading type of tube which is supposed to embody the advantages of the regular spreading type of tube but is somewhat simpler to construct. As far as our experience goes we have been able to notice very little difference in the operation between any of the types of draft tubes that we have. This is undoubtedly due to the fact that all our turbines operate at very high heads so that any increase in efficiency due to the more modern tube is difficult to detect.

Impulse Wheels

The impulse wheels installed by the company in the last two years do not embody any novel features, being duplicates of others that have been in operation for many years. We do have under way, however, a preliminary study of a new plant that will operate under a total head of 2400 feet. At the present time preliminary plans are being worked out for double over-hung impulse units for this plant which will have a capacity of 75,000 horse power per unit. These wheels will undoubtedly be the largest impulse units ever constructed from the standpoint of total output but on account of the high head will probably not be any larger in physical dimensions than the wheels in the Caribou plant of the Great Western Power Company. The chief difficulties to be overcome in the design of a unit of this size are the penstock and the water wheel and generator bearings.

Rubber Seal Rings

For several months we have had in operation a small hydraulic turbine equipped with rubber seal rings. These rings have not been in operation long enough to definitely determine their practicability but it appears that when this type of ring has been fully developed it will have great possibilities. Arrangements are being made to try out these rubber rings on one of the turbines in the Kern River No. 3 plant. This trial will give some valuable information as it will be the first time this type of ring has been installed on a unit of this size.

Upper Falls Development of The Washington Water Power Company in Spokane, Wash.

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Review of the Subject.—*This describes a late hydroelectric development in the center of a city having a single vertical shaft generator and delivering its output to the busses of an existing distribution substation 350 ft. distant, the excitation and load control of the new generator being from the substation. The principal features of the development are the auxiliary devices to assure reliable operation of a remotely controlled unit and provision for an automatic shutdown of the unit in case of major trouble; also the automatic by-passing of a large portion of the water used by the wheel if the load is greatly reduced or dumped. Other features are a 20-ft. diameter reinforced concrete penstock, a Moody spreading draft tube and a large concrete volute casing, reinforced against 110-ft. head; also 60 ft. by 15 ft. gates remotely operated, the operator having before him devices indicating gate travel and elevation of water level being controlled.*

* * * * *

BEFORE the main features of the development that forms the subject of this paper are described, some mention should first be made of the prior developments to which the Upper Falls is an important addition.

The four earlier developments of The Washington Water Power Company totaling 125,000 h. p. as well as the one described, are all located on the Spokane River and utilize succesively the same water with only a small additional inflow between plants.

Spokane River has its source in Lake Coeur d'Alene, a body of water some 42 square miles in area, where a storage and draw down of 5½ feet is possible. A few miles below the outlet of this lake is the Post Falls station which utilizes a head of 50 to 55 feet. At this station, the second one constructed by the company, are located the flood gates by which the lake level, except at times of flood, is controlled.

At Spokane, the next station downstream from Post Falls, there is a rare situation where a city of considerable size has been built up around a series of falls. Here the initial hydroelectric power developments, utilizing about 53 per cent of the total available head within the city, were begun in the very early days of the electrical industry and completed in 1904. This development, known as Monroe Street station makes use of the lower 73 ft. of the available head. The development of the upper head of 64 feet is the subject of this article.

The other two power plants of the company are at Long Lake, utilizing a head of 172 feet, and at Little Falls, which is immediately below Long Lake, where the head is 73 feet.

In addition, Spokane River water operates a part of the pumping equipment of the city of Spokane and the hydroelectric station of the Spokane & Eastern Ry. & Power Company located between Spokane and Long Lake. Unregulated flow of the Spokane River varies from a minimum of about 1200 cu. ft. per second occurring usually in October to a maximum so far recorded of approximately 50,000 cu. ft. per sec. The mean low-water flow is about 1400 cu. ft. per sec.

Lake Coeur d'Alene in turn is supplied from mountain streams having their sources up to 6000 ft. in elevation. Precipitation is mostly in the form of snow and the annual flood, which reaches its peak between May 10th and June 5th is the result of melting snow and is usually over by the 15th of July. There is usually very little precipitation in the drainage basin between July 10 and September 15th and the inflow into Lake Coeur d'Alene from July 15th until the fall rains arrive is the yield from ground storage.

The Spokane plants have practically no storage in their forebays but there is most excellent storage in the forebay of the Long Lake station. Long Lake serves as storage also for Little Falls, which is hydraulically in series, and has power units of the same water capacity as the turbines at Long Lake.

After the passing of the summer flood the gates at Post Falls, which control the level of Lake Coeur d'Alene, are closed and a practically uniform load is carried by the units in this station. Because of lack of storage in Spokane the uniform flow released from the lake passes through unchanged to the forebay of the Long Lake station. This station and the one immediately below it take care of the daily variation in the load carried by the system.

Among the early installations at the Monroe Street station for lighting and power was the so called Edison 3-wire d-c. system to supply the principal business district, and 600-volt., d-c. current for street railway service, the generators being driven by direct-connected water wheels. These have been added to as the demand grew and since 1904 about 4300 kw. of direct-current energy has been produced at this station by water-driven machinery.

A dependable supply of direct-current energy for the Edison system and street railways having thus been in part assured by its production near the center of load, there still remained the problem of a dependable source of a-c. energy for power outside the economic limits of the Edison system and for residential lighting.

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Up to the time of the complete Upper Falls development this a-c. energy was mainly supplied from outside plants by transmission lines which for the most part center in Post Street substation where there are also located the step-down transformers, additional motor-generators, lighting and power feeders, and feeders of the series street lights. To assure for these classes of services a dependable supply of a-c. energy its generation close to the point of feed was needed.

When in 1920 it became apparent that an additional supply of power would be required in the near future it was agreed at once that the next development should be made in Spokane where all necessary water rights had been acquired many years previously and where is also located the principal loads on the company's system. Some physical features of the situation may be gathered from the map of Fig. 1, on which the location of Monroe Street station, Post Street substation and the company's office building are also shown. A profile, taken along the main and middle channel of the river, giving some idea of the elevations that exist here, is shown in Fig. 2.

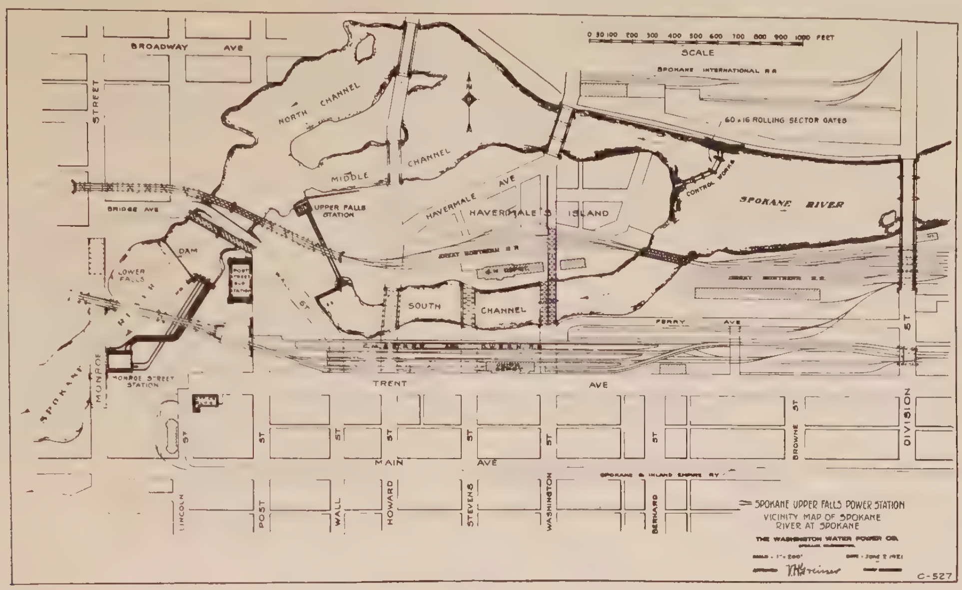

Fig. 1

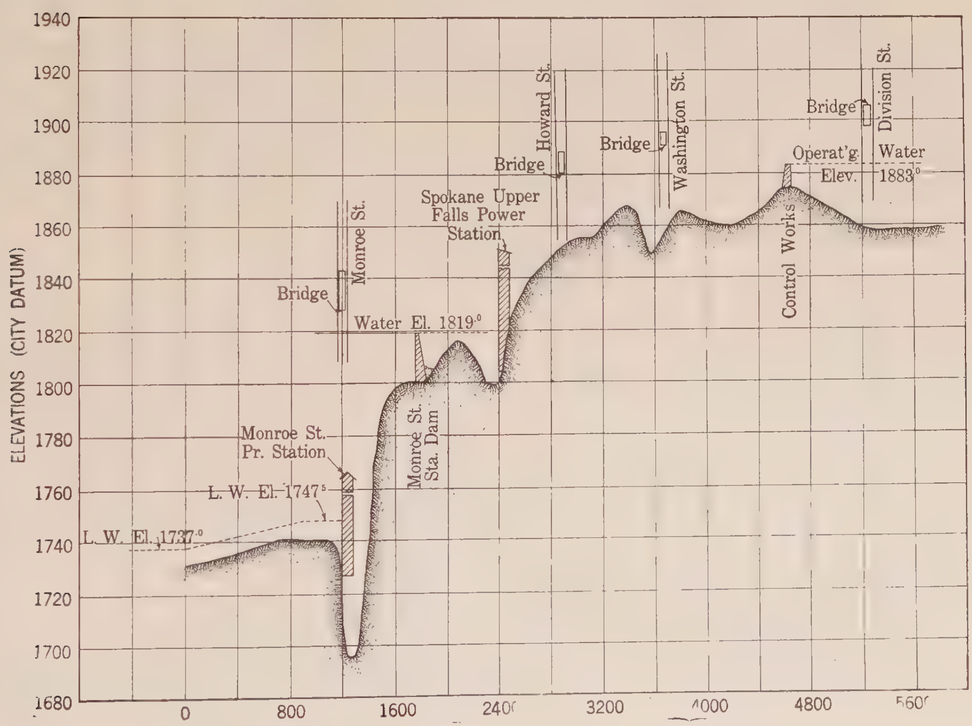

Fig. 2—Profile along Main and Middle Channels of the Spokane River through Portion of Spokane. Scale: Horizontal, 1 In. = 400 Ft. Vertical, 1 In. = 20 Ft.

Originally the south channel rejoined the main stream at the junction of the middle and north channels but this was dammed in the early history of the city and the water utilized to furnish the drive for a sawmill. This water-driven equipment remained in operation up to the time of the Upper Falls development. The water level in the end of the south channel is the same as at the branch of the main stream below Division Street. The shortest distance between the upper and lower water levels is from the end of this channel to the main stream at Monroe Street.

Making the development of the total head in one step was naturally considered first but this required a rather large tunnel of considerable length passing under important structures of other ownerships. Lack of room needed for the new station would have further required immediate abandonment of the Monroe Street station whose equipment, though somewhat obsolete and of low efficiency, still produces energy that can be provided otherwise only by large additional capital investments in transformation equipment with its attendant losses. This would have also duplicated in part an investment already made and still possessed of additional useful life.

Location of the station at the point shown on the map and containing a single a-c. unit generating at the bus voltage of Post Street substation more nearly satisfied the requirements of service protection against interruptions, production of needed energy at the point of feed, a minimum of transmission and transformation, at the lowest cost for investment.

The principal points of interest of this development are as follows:

1. A reinforced concrete penstock 18 ft. in diameter and 370 ft. long.

2. A motor-controlled Johnson valve electrically interconnected with water wheel to open automatically and by-pass a large part of the river flow should the wheel load fall below a predetermined amount.

3. A vertical type water wheel having a concrete volute casing and Moody spreading draft tube.

4. Supply of excitation current and complete control of unit from a distribution station located 350 feet away.

5. Control works designed to pass a flood of 60,000 cu. ft. per sec. and partly under control of the system operator.

Penstock

It was desired to pass a flow of 2200 cu. ft. per second and the conditions which influenced the selection of reinforced concrete were as follows:

The penstock was to connect a concrete headgate dam to a concrete volute casing in the power house.

It had to be constructed in an excavated rock cut, increasing in depth from a few feet at the headgate dam to over 20 feet near the power house. It had to pass for most of its length under a heavy wooden platform used for saw mill purposes, and under lumber sheds thus carrying a heavy fire hazard.

It had to pass under a double track steam railway line and it was desired to make it as resistant as possible to damage from accidental derailment.

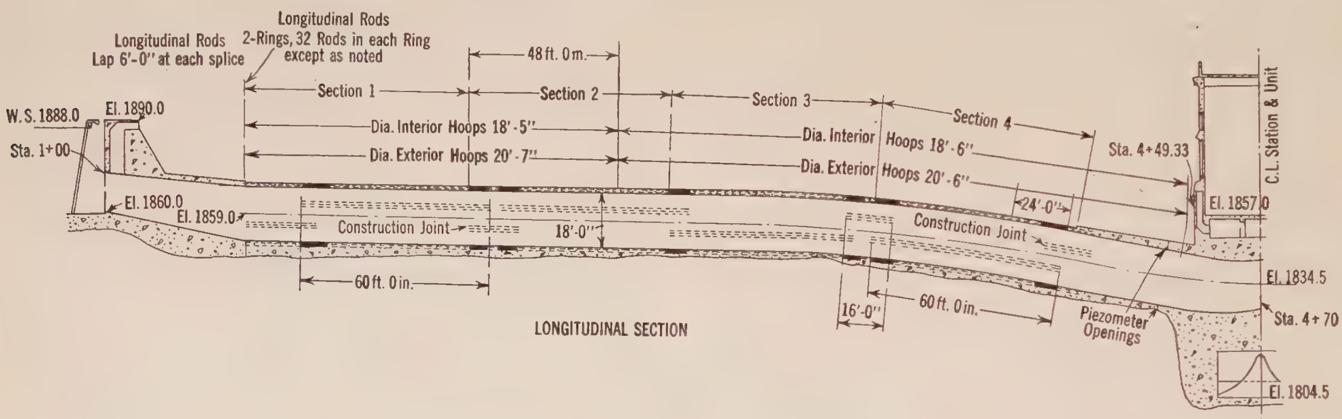

Fig. 3

Since the location would make maintenance and upkeep very difficult it was desired to make the construction of a type least subject to depreciation and decay.

Concrete reinforced with steel satisfied the above requirements to a greater degree than any other type available. Fig. 3 gives the principal construction details.

A few small leaks appeared when the penstock was first filled with water but disappeared after a few months time. There is every reason to believe that the type of construction selected could not have been better.

Johnson Valve

It has been mentioned above that for a large portion of each year this station would utilize the full regulated flow of the stream. The tailrace of this station is the forebay of the older Monroe Street station, with pondage that would be exhausted in a few minutes time.

In case of a sudden shut down of the Upper Falls

single-unit Monroe Street station would cease operating for want of water before the gates at the control works could be opened and the released water reach the forebay through the main river channel.

To prevent this contingency a 9-ft. diameter Y branch was led off from the main penstock within the from the control works arrives in sufficient volume.

Location of the valve, its shape and the supply line branching from the main penstock may be seen in the cross-section of Fig. 4, where this valve is shown open.

Operation of the Johnson valve is from a motor-driven Dean Control unit, the valve starting to open

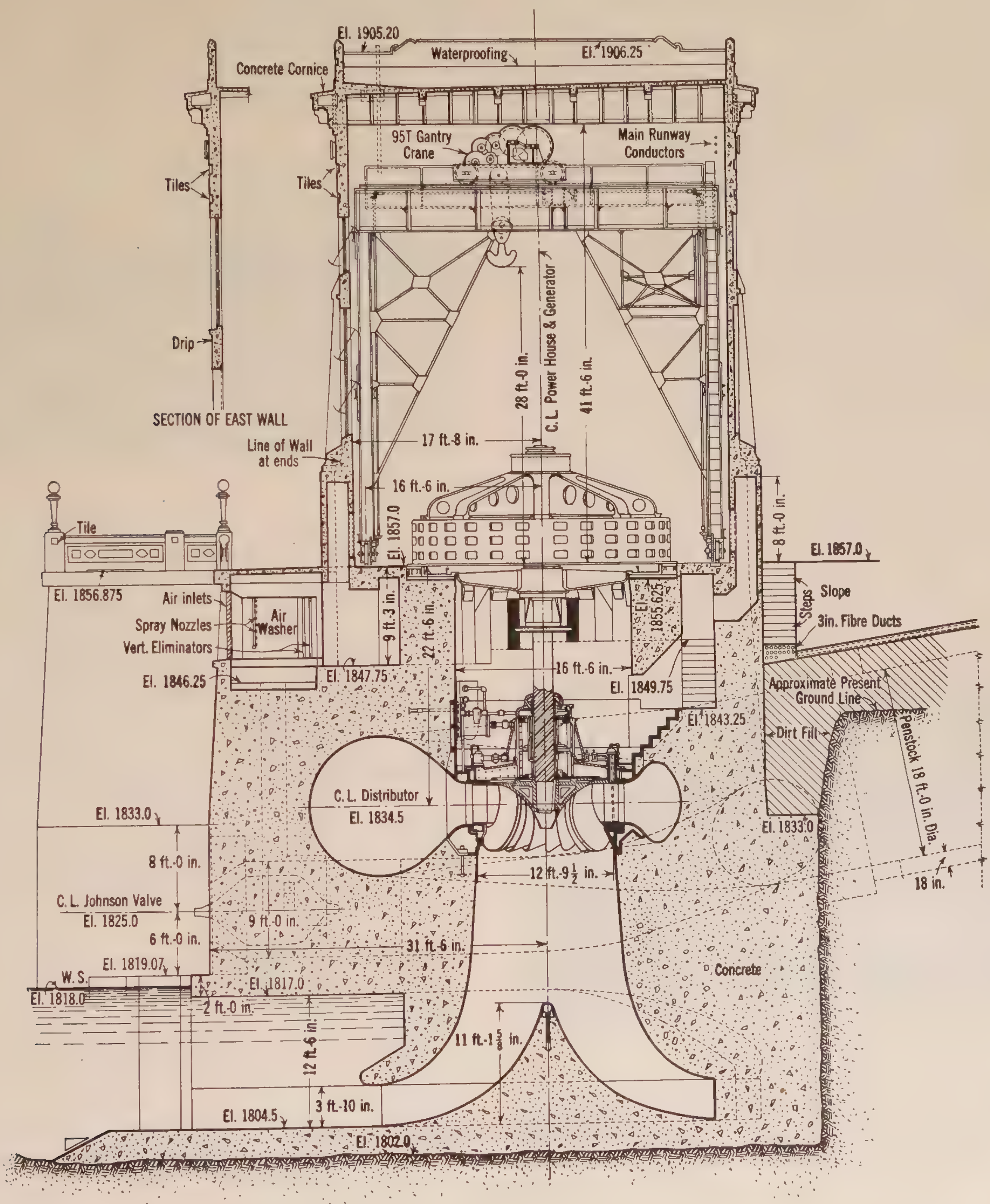

Fig. 4

power house foundations to a 62-in. Johnson discharge regulator located so as to discharge into the tailrace of the station. Under the existing head it is rated to pass 1000 cu. ft. per second and this will keep Monroe St. station operating until additional water released when the servo-motor piston has closed to within 0.25 of its travel and the valve will start to close when this piston has reached 0.4 of its travel in opening. Closed or open positions of the valve are indicated by green and red lights respectively in the generator room of the

power station and also in the System Operator's room in the company's office building. If it is desired to shut down the wheel without opening the valve this is accomplished by simply opening a switch in the motor circuit of the Dean Control unit. This arrangement functions splendidly and has been tried out a number of times within the past 9 months.

Water Wheel, Governor, Casing and Draft Tube

The vertical shaft type water wheel, designed to operate under an effective head of 64 ft. is rated at 14,250 h.p. and contains a cast iron runner of 11 ft. 7 in. maximum diameter, mounted on a steel shaft of 21 in. diameter and revolving at 105.8 rev. per min. A water lubricated lignum-vitae guide bearing, 6 ft. long, steadies the shaft just above the runner.

The volume of water of 2200 cu. ft. per sec. for which the wheel was designed, necessarily involved a large casing which would have made a casing of metal very expensive. The total head, static plus surge at the power house, was found to be close to 110 feet. The "speed ring" or distributor, made of cast iron, was not designed to take any appreciable tension and so it became necessary to reinforce the concrete surrounding the casing as a cantilever beam to resist the upward thrust of the water within the casing. Space does not permit a presentation of the design in detail but some idea of the reinforcement used may be obtained from the photograph of Fig. 5 taken before the concrete around the volute casing was poured.

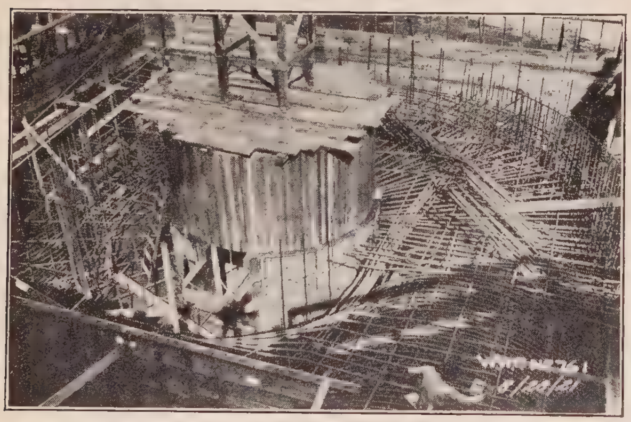

Fig. 5

The peculiar shape of the draft tube, originated by Lewis F. Moody, Consulting Engineer for The Wm. Cramp & Sons Ship & Engine Building Company, builders of the water wheel, may be gathered from the cross-section of Fig. 4. The outlet of the draft tube is through two rectangular openings 19 ft. wide and 12½ ft. high separated by a pier 6 ft. thick.

The governor is the latest design double-floating, lever-type, belt-driven. It is provided with the Taylor Control System which permits of the change from governor control to hand control, and the reverse, to be done by the oscillation through a small angle of a single lever which can be done in the fraction of a second.

Generator, Excitation and Control

The generator, built by the General Electric Company is of the vertical shaft revolving field type, 3-phase, a-c., 60-cycle, 4200-volt, rated at 11,750 kv-a. and 10,000 kw., power factor 0.85.

The revolving weights of generator, water wheel, and hydraulic thrust due to runner amounting to a

Fig. 6

total of 188 tons, are carried by a General Electric Company's spring supported thrust bearing mounted on the generator upper bracket. This bearing is immersed in a bath of oil that is water-cooled and continuously filtered. The circulating oil pump is of the gear type, driven directly from the shaft but a similar motor-driven pump has been installed as an auxiliary.

Guide bearings, supplied with forced lubrication, are placed on generator shaft both above and below the rotor. The generator is provided with air-operated brakes which assist in bringing the rotor to a stop. These brakes are also arranged for a supply of oil from a hand pump up to 1500 lb. pressure which will lift the total suspended weight and thus relieve the thrust bearing.

The generator rotor is equipped with fans for forced air circulation through the stator windings. Supply of air is taken from the outside through an air washer of 50,000 cu. ft. per minute capacity. Air may also be taken in part or totally from the generator room and recirculated.

In the station with the generator are two gear-type oil pumps one of which is driven by an a-c. motor and the other by a d-c. motor, supplied from the Edison System, thus assuring reliability of fluid pressure supply to the governors; also oil pressure and sump tanks for the servo-motors, and a motor-driven, two-stage air compressor connected to a receiver. Air is used in the oil accumulator tank and for the air brakes under the generator rotor.

Here are also located an indicating thermometer showing the temperature of the thrust bearing and a flow

meter showing the quantity of water supplied to the lignum-vitae guide bearing.

The generator mains consist of three, 1,250,000 cir. mil. lead-covered, paper-insulated cables per phase laid in fiber duct embedded in concrete. As there are duplicate feeder busses in Post Street substation to which this unit is connected there are also two circuit breakers, one to each bus, each with its usual complement of disconnecting switches.

An attendant is kept continuously on duty at the power station and he is depended on to look after governor operation, oil pumps and air compressor, water supply to lignum-vitae guide bearing, air washers, and similar tasks. He starts the wheel and brings it up to part speed before turning it over to the switchboard operator at the Post Street substation and also has control of the Johnson valve separate from the interlock with water wheel gates. A Klaxon horn actuated from a pressure gage is used to warn the attendant should the supply of water to the lignum-vitae guide bearing fail for any reason. By means of a controller located in the power station the attendant can also close the head gates of the penstock that supplies this unit.

The motor-driven exciter and the generator field rheostat used for field excitation of the main unit are located at Post Street substation. Should this supply of energy fail an auxiliary supply may be had from the Edison mains connected to a storage battery floating on the system.

Location of the main generating unit of the size of this one in a separate building some distance from the point of control naturally necessitated a number of safeguards to assure reliability of service and to protect the equipment from damage. It is hoped that a brief description of some of them will be of interest.

The generator is Y-connected and, as is now common on generators of like capacity, differential relays have been provided to open the circuit breakers in case of trouble within the machine itself or in the cables leading to feeder busses.

As already explained the power station attendant is relied on to look after governor operation, oil pumps for governor pressure system, and water supply for cooling and lubricating purposes.

Operation may be interferred with, in addition, through any of the following causes which, though they do not require an immediate shut downof the wheel, need to be brought at once to the attention of the switchboard operator at Post Street substation.

Heating of the thrust bearing or guide bearings; failure of supply of lubricating oil to generator guide or thrust bearings; the breaking or slipping off from pulleys of the governor belt.

Warning is given through the ringing of a bell and the lighting of a signal lamp at the Post Street substation switchboard.

Thermal relays, normally closed, are inserted in each of the three generator bearings. A small current is kept circulating through this relay circuit and keeps open, by means of a solenoid switch, an auxiliary circuit containing the bell and light. Should any of the bearings become over-heated this relay will open the circuit. This will de-energize the coil holding open the switch in the auxiliary circuit and thus give the alarm.

Warning of the failure of flow of lubricating oil to the three bearings is given by closing the alarm circuit connected to Richardson-Phenix sight flow indicators, one in each of the supply lines to these bearings.

On the governor belt drive there is a tightener pulley mounted in the small end of a bell crank lever. Pressure against the belt is exerted through the bell crank lever by means of a weight. A switch of an auxiliary circuit, normally open, is mechanically connected to the bell crank lever. Should the belt break or climb off the pulleys the weight will move the bell crank lever far enough to close the switch in the auxiliary circuit. This will in turn effect a closure of the alarm circuit, thus causing the alarm to be given.

A balance coil meter having a scale showing percentages is located in Post Street substation. This is electrically connected to a rheostat in the power station, the rheostat being actuated by a mechanical connection with the water wheel gates. As the gates open resistance is cut out which causes the balanced coil meter at Post Street substation to indicate corresponding gate openings. Thus the switchboard operator can tell at all times at just what gate openings the wheel is working.

It has been mentioned that air-actuated brakes are provided to assist in bringing the rotor to a stop. A rapid or slow application of the brakes may be made. There are two parallel air supply lines, each one controlled by a solenoid-operated valve, leading to these brakes. One of these lines contains a small orifice which has a throttling effect on the air supply. This will cause a slow application of the brakes and a relatively slow shut down which does not cause rapid wear of the brake shoes. This is normally used. The other supply line contains no restriction and its solenoid-operated valve is opened by a solenoid in a circuit interlocked with the differential relays. It is considered that if the differential relays act it is the result of serious trouble requiring a rapid shut down. In that case the application of the brakes is rapid so that the rotor is brought to rest very quickly. Provision is also made for applying the air to the brakes by means of a hand-controlled three-way valve.

Control Works

In order to obtain the maximum possible head throughout the entire year it was necessary to install gates to maintain a practically constant forebay level and pass a flow varying from nothing to an amount in excess of the maximum measured since records have

been kept. Since the forebay extends through a portion of the city it was desired to have means showing the water level at all times and for quickly passing a large volume of flow should the water wheel suddenly lose its load for any reason.

The arrangement adopted was the installation of two motor operated "Rolling Sector" type gates each 60 ft. wide and 16 ft. high, operated either from a control house located on one of the abutments or by the system operator in the office building. Also the provision of four 40-ft. by 11-ft. openings, each closed by five vertical lift gates supported by adjacent piers and four top-hinged girders. One of the rolling sector gates is normally held in reserve while control for a flow up to about 9000 second feet is exercised by the second rolling sector gate. Flows in excess of this are normally passed by clearing the 40-foot openings as needed. A plan of the Control Works is given on the map of Fig. 1 and in Fig. 6, taken when a moderate flood was passing, shows the works with one sector gate open and the other closed.

Each sector gate is operated by a 15-h.p. series d-c. motor mounted in the middle of a bridge spanning between gate piers and controlled either from a drum controller or from a contactor panel, both being contained within a house on one of the gate abutments. Connecting one gate motor through selector switches to drum controller connects at the same time the other gate motor to control by contactor panel. Both systems of control give dynamic braking in lowering and in the off position.

Motor rheostats have been adjusted so that the current on the first point of the rheostat is about three times the value of normal load current. This assures operation even if the contactors should fail to short out the succeeding resistance steps. In lowering there is only one resistance adjusted to suit over-haul of gate.

The contactor panel may be operated from either of two parallel double-throw knife switches one of which is mounted on the contactor panel itself and the other one is in the system operator's room in the office building located some 3000 feet from the gates.

The system operator has mounted above the remote control switch a gate position indicator which shows at once any travel of the gate. Should the indicator fail to show a change in gate position a few seconds after the control switch is closed it is evidence that motor has failed to start and the switch can be opened to prevent burning out of motor and shortly another trial made. Should the supply of power fail for any reason a double acting breaker opens the control circuit and closes the motor circuit for dynamic breaking. This breaker may be reset by a switch in the system operator's room as soon as power is restored and the gate again operated in the direction desired.

There are two power supply circuits for the motors partly under ground and partly overhead, one directly from Post Street substation and one from the Edison mains serving the district adjacent to the Control Works. This arrangement has been found satisfactory in practise and has made it possible to dispense with continuous attendance at the Control Works.

The Upper Falls development was designed and constructed under the general direction of V. H. Greisser, Chief Engineer, assisted by H. L. Melvin, in charge of electrical features and the writer in charge of mechanical and structural work.

TRANSMISSION OF RADIO SIGNALS OF STANDARD FREQUENCY

Notices have been given in past numbers of the Bureau of Standards Bulletin of the transmission of radio signals of standard frequency to enable the owners of radio apparatus to check their wavemeters and to adjust transmitting and receiving sets. Such standard signals were transmitted on October 20 and will be transmitted November 5, November 20, and December 5. The transmission on October 20 was of special interest to commercial and ship operators, since it included most of the frequencies assigned to marine and commercial traffic.

On November 5 signals will be transmitted in the frequency band used by the Class B broadcasting stations. Measurements which the Bureau of Standards has made indicate that a few stations are not remaining on their assigned frequencies and hence are causing interference with programs from their own as well as other stations. This situation can be relieved by using these signals to calibrate a wavemeter which in turn can be used to adjust the transmitting equipment.

On November 20 signals will be transmitted covering approximately the same band as those on October 20, while on December 5, the frequencies transmitted will cover those used by all broadcasting stations as well as some used by amateurs. This complete schedule has been so planned that a wavemeter may be accurately calibrated over a range from 150 to 1700 k.c. provided all the transmissions are received.

The schedule followed in these transmissions will be slightly different from that adopted in the past. All transmissions will be by unmodulated continuous wave telegraphy and no announcements will be made by voice, thus considerably reducing the time of transmitting any one frequency. Details concerning the nature of the signals, together with a complete schedule, can be obtained by consulting the Radio Service Bulletin which can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C.

A Study of Irregularity of Reaction in Francis Turbines

BY ROY WILKINS

Associate, A. I. E. E.

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Review of the Subject.—*Irregularity of reaction in hydraulic machinery causing vibration has up to the last few years been of relatively little importance and treated as a more or less necessary evil.*

With the advent of larger units, particularly for high heads, it became of prime importance that there be little or no vibration. In cases where vibration occurred, a cut and try system of remedying it was usually resorted to and as little publicity as possible given the procedure.

For the study of such phenomena as vibration caused by irregularity of reaction manifesting itself in several impulses per second the electrical methods long since developed are admirably adapted and this paper gives a brief description of a successful method of study.

During the last few months there has arisen an occasion to study the hydraulic conditions causing vibration in some of the Francis type turbines on the system of the company by which the writer is employed.

Preliminary reconnaissance showed that these vibrations had a period in the order of the electrical frequencies commonly used and that for their study special equipment must be used which, so far as is known, had not been developed.

Fig. 1

There was accordingly developed somewhat hurriedly from parts available a device for converting pressure variations to electrical impulses and then viewing or recording these by means of an oscillograph.

As shown in Figure 1 a 1½ in. pipe union was used to hold a diaphragm of spring steel of a thickness such that at the maximum pressure used its deflection is still approximately proportional to pressure change. (Several well known gas engine indicators operate on this principle and it is known to be trustworthy.) Rigidly attached to its center is an arm bearing on its outer end the center elements of two microphones of a variety used commonly in amateur wireless work.

The outer elements or shells of these microphones are rigidly attached by an insulating member to the union in such a manner that the supports are used as current-carrying terminals.

A third terminal grounded to the union makes electrical connection through the arm to the center elements of the microphones.

With the connections as shown the device forms an elementary bridge with microphones and batteries as members and an oscillograph element as a detector. The 2-volt batteries forming two arms of the bridge

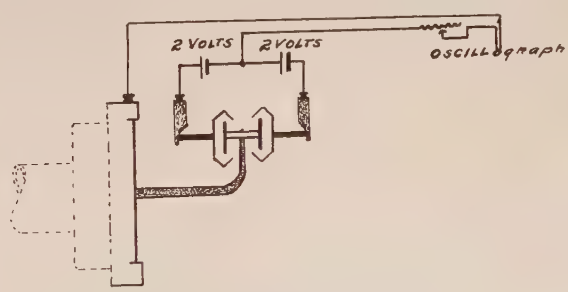

Fig. 2

are so connected that they tend to cause current to flow through the oscillograph element in opposite directions so that as the diaphragm moves due to pressure changes we have a curve resembling an alternating-current curve traced on the oscillograph film proportional to and in correct sequence with the pressure changes back of the diaphragm. The device can be attached to any point that an ordinary pressure gage can and a ½ in. connection if comparatively short is more than ample to actuate it.

Using one of the portable oscillographs now available studies have been made on several turbines under varying conditions of load, head, gate opening, etc., with a view of determining the fundamental reason for vibration. It is known that the pressures across the face of a turbine runner opening vary both from top to bottom and from trailing to leading sides and

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are dependent upon design characteristics as applied to running conditions.

As a check on probable values, tests were made using a Pitot tube traveling with the runner and passing to the center of the draft tube and out through a packing gland either to a pressure gage or the pressure indicator described above.

By filling this rotating tube with air under pressure and then closing, the supply air is trapped under the pressure of the water at the end of the tube and centri-

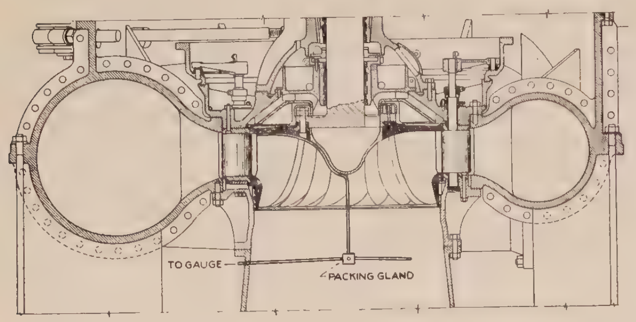

Fig. 3

fugal action and leakage are minimized. In this way the whole face of the runner entrance may be explored under actual running conditions.

Having established the fact that there is a difference in pressure on the water over the entrance of a runner bucket gives us a clue to the reason for the changes in pressure on the scroll case and penstock supplying it because as a low-pressure area in the runner is presented to the guide vane opening, the water velocity is augmented, while when a high-pressure area is presented the entering velocity is checked.

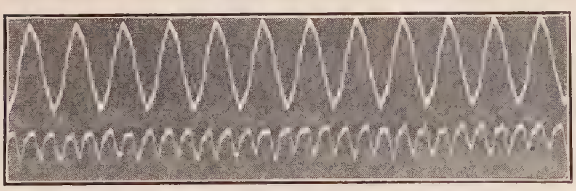

Fig. 4—5000 Kw., 220 Lb., 450 Rev. per Min., 19 Runner Vanes, 20 Guide Vanes. Hum Apparent in both Power House and Pen Stock. 15 Ohms in Vibrator

This difference in pressure has been measured where the difference between leading and trailing sides of the runner entrance pressures was approximately 10 per cent of the total head on the turbine.

If we have a turbine in which the number of runner vane openings $(n-1)$ are one less than the number of guide vane openings (n) the openings will register successively around the scroll case each $1/(n-1)$ revolution as a vernier backward from the direction of rotation.

This gives $(n-1)$ impulses per revolution or the revolutions per second times the number of runner vanes in impulses per second.

A difference of two in the number of guide and runner vanes gives two impulses traveling at half speed around the scroll case while combinations such as 20 and 17 gives irregular impulses. These combinations are best studied on small drawings to scale on cardboard, the runner portion of which may be rotated by hand.

Fig. 4 shows a pressure curve of a turbine having 20 guide vanes and 19 runner vanes with a timing wave of 60 cycles. This gives the Vernier action described above and the machine has a decided hum and a vibration which persists with gradually lessening intensity up the penstock 3600 feet to the forebay where it is scarcely perceptible.

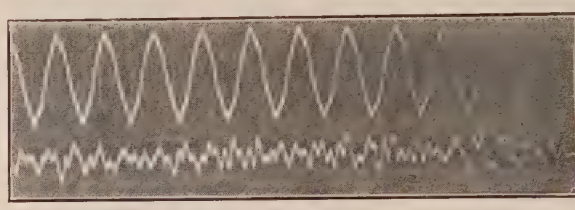

Fig. 5—5000 Kw., 220 Lb., 450 Rev. per Min., 17 Runner Vanes, 20 Guide Vanes. No Apparent Noise or Vibration 15 Ohms in Vibrator

Fig. 5 shows the curve from an identical scroll case with 17 runner vanes and a 60-cycle timing wave. In this case there is apparent neither hum nor vibration yet the curve shows just as high a hydraulic pressure variation which is, however, not regular.

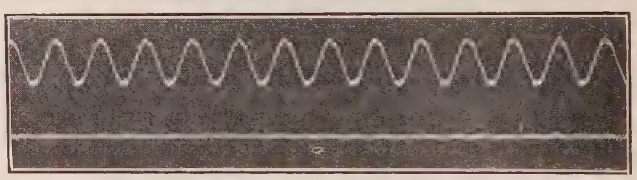

Fig. 6—5400 Kw., 238 Lb., 400 Rev. per Min. No Noise or Vibration. 15 Ohms in Vibrator. 20 Runner Vanes, 24 Guide Vanes

Fig. 6 was taken on a turbine of somewhat older design and different specific speed and is almost ideal as regards hydraulic vibration. Just a slight wave may be traced which corresponds to the frequency we would expect.

Fig. 7 is an example of a combination of 18/16 and in operation this machine has a perceptible hum and vibration which persists up to the forebay 1600 feet from the turbine.

There are some conditions under which this is more pronounced than others due to the manner in which the water enters the runner.

Fig. 8 is a high-speed film on large ordinates of a record of a turbine with a 20/19 combination of guide and runner vanes taken to study the effect of the guide

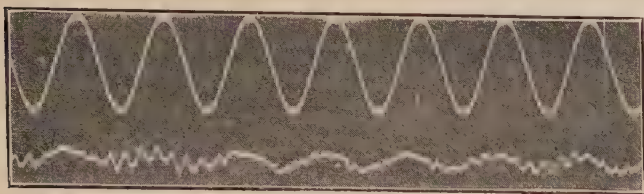

Fig. 7—4600 Kw., 3.34 Gate, 83 Lb. Pressure, 3.5-In. Vacuum, 15 Ohms in Vibrator, 18 Guide, 16 Runner Vanes

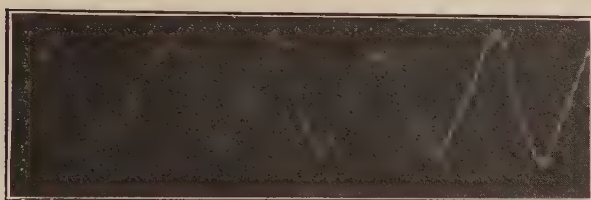

Fig. 8—Film 8-A Vib. No. 2-3w., No. 1 Machine Full Load. 60 Cycles Timing Wave

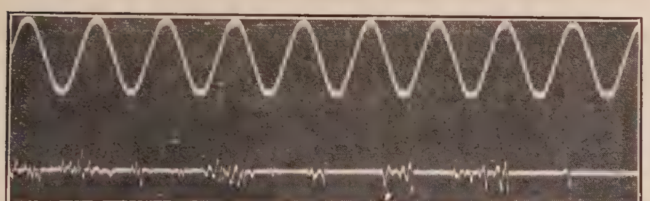

Fig. 9—Film 12-c. Vib. No. 2-15w. Velocity Pressure at Inlet Side of Runner on Axis of Guide Vanes. No. 2 Machine 22,500 Kw. 40 Lb. Back Pressure on Pipe. Timing Wave 60 Cycles

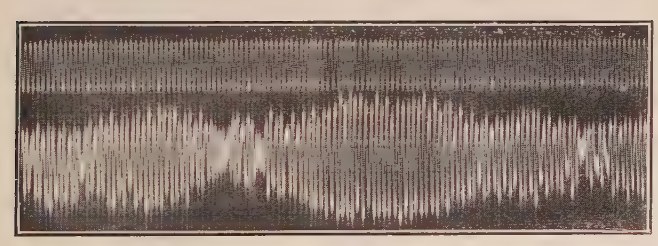

Fig. 10—Film 5-c. Vib. No. 2-15w. No. 1 Pipe Line just Above Pier at End of Tunnel. No. 1 Turbine, Full Load No. 2 Off. Timing Wave 60 Cycles

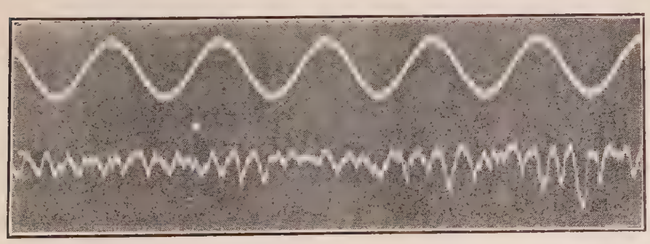

Fig. 11—5000 Kw., Penstock Pressure, 218 Lb., 360 Rev. per Min., 15 Ohms in Vibrator

vanes; a ripple corresponding to each guide vane appearing in the pressure wave.

Fig. 9 is a record of a traverse around the scroll case at the center of the runner opening taken with the rotating pipe referred to above to see if pressure conditions were uniform around the entire circumference.

Little ripples caused probably by the scroll case guides, that is, the fins back of the guide vanes at points around the scroll case to direct the water into the guide vanes are evident though of no particular importance.

Fig. 10 shows the condition in a large somewhat elastic pipe line connected to a turbine having a uniform vibration. Here the pressure waves are

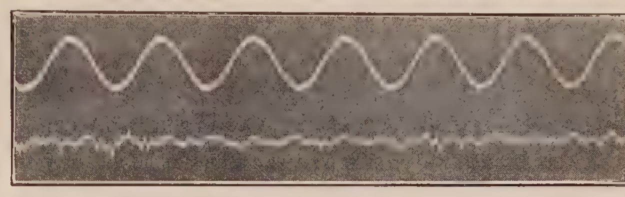

Fig. 12—12,600 Kw., 202 Lb. Penstock Pressure, 360 Rev. per Min., 15 Ohms in Vibrator

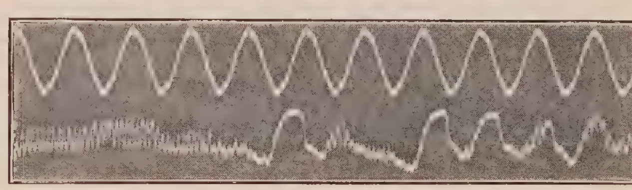

Fig. 13—3240 Kw., 60 Cycles, Pressure Scroll Case 59 Lb., Penstock 72.8 Lb. Draft Tube 4½, Gate 6/8. Relief Valve Closed. 20 Guide 16 Runner Vanes

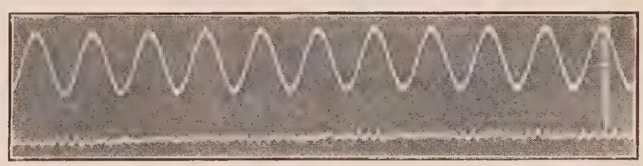

Fig. 14—4470 Kw., 60 Cycles. Pressure Scroll Case 65 Lb., Pressure Penstock 65 Lb., Draft Tube 3½, Gate 7/8, 20 Guide, 16 Runner Vanes

influenced by reflection at the natural period of the penstock, by draft tube variations and by irregularity of flow in the penstock itself.

Fig. 11 shows a turbine in which the flow conditions are critical at a certain gate opening, that is, the pressure difference across the runner inlet face is greater at this particular opening than at others, though not serious on any.

Fig. 12 shows the same machine as Fig. 11 with a greater gate opening.

Fig. 13 shows a curve for a turbine on which abnormal conditions of head and load were imposed. The flow relations were unstable and were manifest in irregular vibrations or "shivers" of the unit.

Fig. 14 shows the same turbine under more nearly normal conditions.

The mechanical vibration was about in the proportion of the curves and there was very little hum on account of the irregularity of pressure variations and the lack of elasticity in the equipment.

All of the curves shown have a 60-cycle timing wave for comparison.

Operation of Apparatus

In taking such records the so-called auxiliary data are of as much importance as the record itself and all conditions should be faithfully recorded in order to study and fully appreciate all of the changes made evident by a film of pressure variations.

Only ordinary precautions are necessary in using the apparatus such for instance as making sure that there is no trapped air behind the diaphragm, that all electrical connections are good and that the oscillograph is properly adjusted and handled.

The microphones are adjusted originally by disconnecting one microphone lead and observing the shift in the zero line caused by current through the one connected and then repeated with the other, adjusting until the shift is the same for each. The adjustment in the present device consists in moving the microphone shell in or out a small distance with respect to the *centrai* part fast to the diaphragm.

It is but a few minutes work to set up and observe the waves and changes in pressure waves may be watched while operating conditions are changed. Once adjusted, different points may be explored wherever a half-inch pipe connection can be made.

Nearly all of the cases studied have to do with the manner in which the water enters the runner and are fundamental in turbine design.

It is thought that the shock due to sudden changes in velocity of moving water has not been fully appreciated in many cases.

Using the ordinary formulas for surges and water hammer as given in Prof. Durand's Hydraulics of Pipe Lines it is seen that with 80 cycles per second, that is, 160 changes, there is required somewhat less than four one hundredths of a foot change in velocity per second to cause 100 lb. pressure change, provided all of this change were effective.

Elasticity in the scroll case and penstock and large clearances between guide and runner vanes together with the combinations of guide and runner vanes which set up conflicting pressures all tend to prevent the difference in pressure across a runner opening from causing high-pressure variations in the scroll case and penstock.

Certain design characteristics cause most of the energy in the water entering the runner to be in the form of velocity and therefore incapable of causing any of the phenomena observed. In other designs more reaction and therefore more pressure is necessary and greater care must be used in entrance angles and clearances.

The subject is as yet very new and very little concerning it is known. It is only hoped that such work as has been done may be of assistance in further study.

LOCATING MINERALS BY ELECTRICAL METHODS

For many years efforts have been made to find a practicable method of locating mineral deposits by the use of electricity. Too often these have proved of doubtful efficacy, or too extravagant for commercial use. Based upon observations made in this country by Daft and Williams, that, in general, minerals of a metallic nature are better conductors than the surrounding body, and that this difference in conductivity gives rise to large distortions of an electric field, a new method has been devised by two Swedish engineers for mineral detection. The electrical resistance of haematite ore is roughly five million times less than that of ordinary gneiss, and of pyrites roughly two million times less. Most metal-bearing ores have resistances between these two extremes. Even ores dispersed through a rock matrix have much higher conductivities than are found with rock containing no ore matter, although the ratio between conductivity and the dispersed ore content has not been exactly determined. Because of this great difference of conductivity, metallic ores attract towards themselves the lines of electric flux, and there is an abrupt change in the currents where the transition from rock to ore body occurs. This abrupt change is noticeable whether the mineral is compact or consists of impregnations. It is unfortunate that the conductivity of water is intermediate between that of rock and metal-bearing minerals, so that the presence of a water pocket will lead to misleading results in the hands of an inexperienced operator. However, water is not usually so sudden in its effects upon the electric flux as a mineral body, and its presence may usually be distinguished without error.

The principle of the method consists in creating an electric field on the surface of the ground to be explored, and determining the lines of equipotential by means of a telephonic circuit. The electrodes comprise two long cables of galvanized steel, and alternating current at 220 volts is produced by a small hand or motor operated generator. The exploring telephone circuit contains metallic pegs which are pushed into the ground; equipotential lines are mapped out by listening in the telephones until no noise is heard. This system has been used in Sweden and Finland with success, and has been taken up by the Geological Service of Sweden. —*Beama.*

Education for the Functional Divisions of Engineering

BY EDWARD BENNETT
Fellow, A. I. E. E.
Prof. of Electrical Engineering, University of Wisconsin

Review of the Subject.—*The functional divisions of engineering are considered to be those functional divisions found within the highly organized industrial organizations,—namely, research, design, supervision (of physical plant and of physical and chemical processes), management (of labor and business features) and engineering sales.*

To provide a background for the discussion of the proposed reorganization of the engineering courses along these functional lines, the features of the existing engineering courses are first presented and briefly discussed. It is pointed out that the existing courses, while intended to provide a broad foundation for engineering work in general, are each intended to provide a more thorough and specific foundation for work in some one of the industrial divisions of the engineering field.

The grounds for selection between the existing engineering courses are then discussed. The question is discussed as to whether the student and his counselors would not be required to consider and to choose between the more basic types of engineering if each major engineering course were laid out to provide the best foundation for one of the functional divisions of the engineering field.

The general features of the proposed functional courses are discussed and contrasted with those of the existing courses. The need for more than one type of treatment of many of the subjects is presented and the conclusion is drawn that the distinctive general feature of the functional engineering courses should be the separate provision for the needs of men of superior aptitude and for those of moderate aptitude by profoundly technical and moderately technical treatments of the different branches of science, particularly of the mathematics and physics of the first two years. The distinctive features of each of the functional engineering courses and the conditions of transfer from one to the other are discussed.

The merits and possibilities of a method of determining the student's aptitude for the work in an engineering college before enrolling him in the college, by requiring him to report before the opening of the school year for a month of work and counsel with mature educators, are pointed out. The closing discussion relates to the relative parts played by survey courses and by profoundly technical courses in the development of clear, trustworthy breadth of vision.

* * * * *

Purpose

PERHAPS the most serious, clear-cut, and specific criticism which can be made of the existing courses of engineering study is to the effect that they bring new topics to the attention of the student in such numbers and with such rapidity that he cannot adequately meditate upon, or review and correlate the flood of new half formed ideas. The result may be the formation of the habit of confused or of superficial thinking.

Now, strange to say, in a number of the discussions of engineering education, the superabundance of the subject matter which may be offered in a specific course, or the "congestion" of the specific course, (for example, Civil Engineering, Railway Option) has been attributed to what is termed the subdivision and *specialization* of the engineering courses of study. Other undesirable effects, such as narrowness of vision, have been attributed to *specialization*. These imagined evils of specialization have been so persistently presented that the tendency in more than one college is to make all the engineering courses of study identical in content for one, two or three years for the entire group of engineering students. As a matter of fact, at the present time, all the engineering students at any given college have substantially two years of work in common, the greater part of which occurs during the first two years of the four year courses.

In striking contrast to these courses, this paper presents for consideration courses of study in which the fundamental studies of the first two years are not identically the same in all courses, but are avowedly different both in content and in aim. Each of these courses is intended to provide the foundation for what may be designated as one of the *basic types* of engineering work or as one of the *functional divisions* of the engineering field. In this paper, the functional divisions of engineering are considered to be the five divisions listed and concisely specified in Table I, and more fully specified in Table II.

TABLE I.

Basic Types or Functional Divisions of Engineering

I. Engineering Research.
- Of the analytical-physical type—Faraday.
- Of the analytical-mathematical type—Heaviside.

II. Engineering Design.
- A. Of appliances and machines.
- B. Of structures.
- C. Of plants or systems or projects.

III. Engineering Supervision. (Having oversight of physical plant and physical and chemical processes.)
- A. Manufacture of materials, machines and appliances.
- B. Construction, erection and installation.
- C. Operation of utilities.

IV. Engineering Management. (Having oversight of artisans, machine operators and business features in the engineering industries.)
- A. Manufacture of materials, machine and appliances.
- B. Construction and erection.
- C. Operation of utilities.

V. Engineering Sales

Plan

To provide a background for the discussion of the proposed reorganization of the engineering courses along these functional lines, the features of the existing engineering courses are first presented and briefly discussed. It is pointed out that the existing courses, while intended to provide a broad foundation for engineering work in general, are each intended to provide a more thorough and specific foundation for

work in some one of the industrial divisions of the engineering field.

The grounds for selection between the existing engineering courses are then discussed. The question is discussed as to whether the student and his counselors would not be required to consider and to choose between the more basic types of engineering if each major engineering course were laid out to provide the best foundation for one of the functional divisions of the engineering field.

The general features of the proposed functional courses are discussed and contrasted with those of the existing courses. The need for more than one type of treatment of many of the subjects is presented and the conclusion is drawn that *the distinctive general feature of the functional engineering courses should be the separate provision for the needs of men of superior aptitude and for those of moderate aptitude by profoundly technical and moderately technical treatments of the different branches of science, particularly of the mathematics and physics of the first two years.* The distinctive features of each of the functional engineering courses and the conditions of transfer from one to the other are discussed.

The merits and possibilities of a method of determining the student's aptitude for the work in an engineering college before enrolling him in the college, by requiring him to report before the opening of the school year for a month of work and counsel with mature educators, are pointed out. The closing discussion relates to the relative parts played by survey courses and by profoundly technical courses in the development of clear, trustworthy breadth of vision.

The Existing Courses of Study

Table III shows the customary lines along which the engineering courses of study are at present organized in the great majority of the Engineering Colleges of the country. The options listed under each major division are not all to be found in any one engineering college. The course in architecture is not listed or considered in this paper, since its content is very different from that of the other courses.

TABLE III.

THE EXISTING COURSES OF ENGINEERING STUDY

(Emphasizing the industrial divisions of engineering)

I. Civil Engineering
- General option
- Railway option
- Structural option
- Sanitary and municipal option
- Hydraulic option
- Highway option
- Reinforced concrete option
- Architectural engineering option

II. Mining and Metallurgical Engineering
- Mining option
- Geological option
- Metallurgical option
- Ceramic option

III. Mechanical Engineering
- General option
- Machine design option
- Steam power option
- Internal combustion engine option
- Automobile option
- Aeronautical option
- Textile mill option
- Heating, ventilating and refrigerating option
- Industrial management option
- Ordinance option
- Marine engineering option
- Railway mechanical option

IV. Electrical Engineering

The catalogs rarely have the elective studies in the electrical engineering course grouped into options.

V. Chemical Engineering
- General option
- Gas and fuel engineering option
- Organic industrial option
- Pulp and paper manufacturing option
- General chemical manufacture option
- Electrochemical option

VI. Administrative Engineering. (Also called industrial Engineering and Commercial Engineering.)
- Civil option
- Electrical option
- Mechanical option
- Chemical option

The features of these courses are as follows:

a. In any given engineering college, the studies in the freshman year of all these courses are either identically the same, or so nearly the same, that a student who enrolls in one course and then at the end of the freshman year desires to transfer to another, may do so without incurring any handicap whatsoever.

b. From 50 to 60 per cent of the specified studies in any course (the percentage being computed on the basis of the time allotted to each subject) are identical with the specified studies in every other course. The greater portion of these common studies comes during the first two years of the courses. Therefore a student may without loss of credit transfer from one engineering course to another at the end of the sophomore year.

c. The studies which are not only common to all engineering courses, but which in any given engineering college are identical in content and type of instruction for all engineering students are listed in Table IV. The average time allotted to each study is given in per cent of the total time in the four year course.

TABLE IV.

STUDIES COMMON TO ALL ENGINEERING COURSES

	Per Cent
Algebra, Trig., and Anal. Geom.	7
Differential & Integral Calculus	6
Mechanical Drawing & Des. Geometry	6
Chemistry & Qual. Analysis	5
Physics	7
English	4
Statics & Dynamics	3
Mechanics of Materials	5
Thermodynamics	4
Engineering Specifications	2
Non-professional electives	8
Total	57 per cent

d. From 10 to 20 per cent of the time in the four year course is devoted to studies which in name are common to all courses, but which in content and type of treatment are somewhat different for students in the different courses.

e. The remaining time,—from 40 to 25 per cent of the total time in any four year course,—is devoted to studies which are not ordinarily taken by students in other courses.

The fact that the existing courses are identically the same to the extent of 50 to 60 per cent of their content is evidence that the common aim is to provide a broad foundation for engineering work in general. In addition to this, each of the courses or options is directed toward one of the *industrial divisions* of the engineering field, or it is intended to give the student a more specific and thorough preparation for work in one of the industrial divisions of engineering. In fact, the courses in mechanical, electrical, and chemical engineering were gradually evolved in the above order, and were added to the original course, (civil engineering), in response to the increasing importance of the engineering applications of science in these new fields.

TABLE V.
THE INDUSTRIAL VERSUS THE FUNCTIONAL DIVISIONS OF ENGINEERING

INDUSTRIAL DIVISIONS (Only a few are listed)

FUNCTIONAL DIVISIONS	Civil				Mining			Mechanical			Electrical			Chemical		
	Railway	Structural	Sanitary	Hydraulic	Mining	Geological	Metallurgical	Steam Power	Internal Combustion	Heating & Ventilating	Communication	Electric Railway	Power Supply	Gas & Fuel	Chem. Mfg.	Organic Industrial
Sales																
Management																
Supervision																
Design																
Research																

Table V is an attempt to emphasize a relation between the *industrial divisions* of the engineering field and the *functional types* of engineering work. The functional types have been represented by horizontal bands or compartments and the industrial divisions by vertical columns. The horizontal bands cut through all the vertical columns. That is, the design type of work, for example, runs through all the industrial divisions, or on the other hand, any industrial division runs through or comprises all functional types of work.

As stated above, the existing courses and options (with the exceptions of administrative engineering) aim to give the student a more specific preparation for work in the field represented by some one of the vertical columns of Table V, and not a more thorough preparation for work in the field represented by some one of the horizontal rows of the table. The preparation of men for engineering research as contrasted with the preparation for engineering supervision or engineering management receives scant and belated consideration in the existing courses.

The Grounds for Selection Between the Existing Engineering Courses

The ground upon which a student elects a particular one of the existing engineering courses is that the particular course is directed toward that industrial division of the engineering field which for one reason and another makes the greatest appeal to him or to his advisers. Let us now imagine that the existing industrially aimed courses,—civil, mining, mechanical, electrical, and chemical engineering,—were to be replaced by the functionally aimed courses, engineering research, design, supervision, management, and sales. Clearly, the ground upon which a student would then elect a particular one of these major courses would be that the particular course is directed toward that functional type of engineering work which for one reason and another makes the greatest appeal to him.

In which of these situations,—the former or the latter,—will the prospective engineer and his counselors, (parental, high school, and university), be called upon and permitted to consider and to choose between the more basic divisions or basic types of engineering,—*basic in the sense of being founded upon the natural aptitudes, the peculiar type of intellectual interest, or the type of presentation of the introductory studies which is conducive to the fullest achievement in each division?*

Is not the industrial division which the young man elects, or eventually works into, determined very largely by fortuitous experiences and circumstances? On the other hand, is not the *type* of engineering work into which the man eventually works, determined more largely by innate or natural ability and to a much smaller degree by fortuitous events?

These same questions may be raised in a somewhat different form. Let us imagine a situation in which

the engineering educators are so deeply impressed with the importance of vocational guidance that mature educators with a broad conception of the diversified needs of the engineering field are studying the characteristics and qualifications of individual students as evidenced by the work and the reactions of these students in small classes in such important introductory studies as engineering mathematics and engineering physics. Can you conceive of anything very constructive resulting from such an ideal provision for personnel work if the advice of the engineering counselors to the student is couched in terms of the existing major courses of study in language such as the following?

"It seems to us, Jones, that you have the qualifications for a successful career in mechanical engineering and that you would do well to take the mechanical engineering course. In our judgment you should not take the electrical engineering course."

Is it not extremely probable that the advice would be couched primarily in terms of the types of engineering work in some such language as the following?

"It seems to us, Smith, that you have the qualifications for a successful career in engineering supervision or engineering management and that it would be well for you to take either one of the corresponding courses, preferably the latter. In our judgment you are not fitted to succeed in engineering research."

Basic Types and Functional Divisions of Engineering

As stated above, the expression "basic types or more basic divisions of engineering" is being used in this paper to signify those divisions which are founded upon the natural aptitudes, the peculiar type of intellectual interest, and the type of presentation of the introductory studies which is conducive to the fullest achievement in each division.

In my opinion, the basic types of engineering are indicated by the functional divisions within any of the highly organized industrial organizations. Table I is a list of those functional divisions which are entered by engineering graduates in large numbers. For the work of these divisions, an engineering course of study is either the necessary prerequisite or an excellent preparation.

General Features of the Functional Engineering Courses as Contrasted with the Features of the Existing Courses

Let us consider the general features of courses of study each of which is intended to provide the best foundation for one of the functional divisions of engineering. The names of such courses have been listed in Table II.

One feature in which these courses will, in my opinion, resemble the existing courses is as follows: Under each of existing engineering courses, (civil, mechanical, etc.) there are certain options between which a selection may be made late in the course. Likewise, under each of the proposed basic courses, there will necessarily be options between which the student may elect late in the course. Accordingly Table II contains under each of the five courses, a partial list of the subjects or the sections of the engineering field in which the student may elect to major late in the four year course, or perhaps in a fifth year. This list of optional majors is very incomplete. Its main purpose is to convey some conception of the field of each functional group of engineers. It will be seen that this list of majors corresponds to the industrial divisions.

TABLE II.

Proposed Organization of the Engineering Courses
(Emphasizing the functional divisions of engineering.)

I. *Engineering Research*
- A. Of the analytical-physical type—Faraday
- B. Of the analytical-mathematical type—Heaviside

Majors
- Thermodynamics
- Electrodynamics
- Metallurgy
- Physical Chemistry
- Organic Chemistry
- Mathematical analysis
- Hydrodynamics

II. *Engineering Design*
- A. *Of appliances and machines*
  - a. Manufacturing features
  - b. Mechanical features, stress, deformation, vibration, friction
  - c. Electrical features
  - d. Chemical and thermal features
  - e. Thermodynamic features
  - f. Hydrodynamic features
- B. *Of structures*
  - a. Foundations
  - b. Steel structures and frame works
  - c. Reinforced concrete
  - d. Ships
- C. *Of plants or systems*
  - a. Industrial plants (mills, metallurgical, chemical, textile, etc.)
  - b. Steam power plants
  - c. Gas plants
  - d. Hydroelectric plants
  - e. Mining plants
  - f. Systems of communication
  - g. Systems of transportation
  - h. Systems of remote control
  - i. Systems of power transmission
  - j. Heating and ventilating systems
  - k. Sewage systems

III. *Engineering Supervision.* (Having oversight of physical plant and physical and chemical processes.)
- A. *Manufacture of materials, machines and appliances*
  - a. Inspection and test
  - b. Master mechanic
  - c. Plant engineer
  - d. Plant chemist
  - e. Service department

B. Construction, erection or installation
- a. Excavation and tunneling
- b. Railway construction
- c. Building construction
- d. Bridge construction
- e. Dam and flow line construction
- f. Highway construction
- g. Power line construction

C. Operation of Utilities

Maintenance and operating engineers in
- a. Transportation systems
- b. Power supply systems
- c. Gas supply systems
- d. Water supply systems
- e. Systems of communication

IV. Engineering Management. (Having oversight of artisans, machine operators, and the business features in the engineering industries listed above under engineering supervision, *viz.*).
- A. Manufacture of materials, machines and appliances
- B. Construction or erection
- C. Operation of Utilities

V. Engineering Sales
- A. Of engineering materials (wire, oils, steels, cement, etc.)
- B. Of service (transportation, communication, power)
- C. Of machinery (electrical, mining, steam, hydraulic, mill, excavating, pneumatic, gas, ventilating, etc.)
- D. Publicity

The fundamental difference, as I conceive it, between the existing courses and those suggested is this: Under the existing courses all engineering students in any given college receive precisely the same drill in the same subjects for a total period of two years. (All of these subjects do not necessarily come in the first two years.) This is what might be expected in a system in which no attempt is made to classify students in groups other than civil, mechanical, electrical, etc. This classification gives little indication of the aptitudes of the groups, or of the type of treatment of the introductory studies which will be to the best interest of each group. Suppose, however, that the students were intelligently enrolled as students in engineering research, engineering design, engineering supervision, etc. Is it at all likely that precisely the same introductory drill in mathematics, chemistry and physics would be prescribed for all these groups, each of which may now be assumed to be reasonably homogeneous within itself as regards certain professional aptitudes and needs, and to differ markedly from the others? Is it not extremely probable that at least the first two of the three distinct types of treatment listed in Table VI would be available to engineering students in physics and in first and second year mathematics?

TABLE VI.

TYPE OF TREATMENT OF SUBJECTS OF STUDY

Proufoundly technical treatment

Adapted to the needs of men with superior aptitude and keen interest in the subject. Object: to facilitate the acquirement of a *profound understanding* of the subject.

Moderately Technical treatment

Adapted to the needs of men with a moderate aptitude and moderate interest in the subject. Object: to facilitate the acquirement of skill or *proficiency* in the use or application of the principles of the subject to the *moderate* extent necessary to effective work in the man's natural field.

Non-technical treatment

Adapted to the needs of men who have either little aptitude for, or a non-professional interest in, the subject. Object: to facilitate the acquirement of a *non-technical appreciation* of the general content, the methods, and the possibilities of the science.

In the existing courses, the advisability of having at least the last two types of treatment for subjects which are introduced in the latter half of the course, is recognized. For example, all engineering students take studies which are labeled either electrical engineering or electrical machinery, but the introduction of the electrical group to the subject is invariably of the technical type, while the introduction of some of the other groups is, in many colleges, avowedly of the non-technical type. The profoundly technical type of treatment is made impossible for any group because of the prevailing (though not universal) practise of not differentiating in any way in the early electrical studies of the students enrolled in electrical engineering.

In the customary administration of the important introductory engineering studies, mathematics, physics and chemistry, in the existing courses of study, there is no recognition of these three types of treatment. Administratively all engineering students (including those in the administrative engineering courses) look alike for the purpose of the first enrollment in mathematics. Well before the end of the first semester, the instructors have the students classified as of all shades of gray from black to white. But administratively, that is, in so far as provision in the curriculums is made, there are no grays. For the purpose of enrollment in the second semester there are two colors only: white (excellent, good, fair, poor, and condition),—and the whites all look alike,—and black (fail). And thus the work in mathematics is administered for a period of two years. That is, during this entire period there is provision for but one type of mathematical course,—a course in which the treatment is a compromise between the first and second types of Table VI (It should be understood that the above is a presentation of the features of the existing *curriculums*, which of necessity are somewhat inflexible. It would be a gross misconception to suppose that the same inflexibility characterizes the work of the instructor with his students.)

The introduction to mathematics or to physics which is suited to the needs of the engineering management group is not suited to the needs of the engineering research group. The compromise course in mathematics is neither adapted to the needs of the men with superior mathematical aptitude nor to those with moderate aptitude. The situation is about as follows:

a. The growth along mathematical lines of the upper 15 per cent of the men in *freshman mathematics* (the excellence and high goods) is stunted by reason of the trivial nature of much of the class discussion.

b. The course is fairly well adapted to the next 15 per cent.

c. If the customary courses in engineering mathematics were made more *moderately technical* by eliminating from 30 to 50 per cent of the present content, and if the time thus made available were devoted to practise in the application of the fundamental mathematical methods to the simpler engineering problems, the next 30 to 40 per cent of the class might be expected to become moderately proficient in the use of the simple methods.

d. The remaining 40 to 30 per cent of the freshman class are so lacking in analytical ability, or in quantitative sense, as to be unsuited for even the moderately technical treatment of mathematics outlined in the paragraph above, and are out of place in an engineering college.

In my opinion, the above is a fair statement of the conditions obtaining under the industrially aimed courses. The situation is generally recognized and acknowledged, and in the past discussions of engineering education before this institute there is frequent reference to "the educational crime of keeping the able students back at the level of the lowest in the class." Numerous small scale attempts to improve the conditions have been made from time to time, and are still being made. Yet the situation continues to exist, and there is no large scale or concerted move to remedy it.

It hardly seems possible that educators could work under courses entitled engineering research, engineering design, engineering management, etc., for a score of years and be so backward in making provisions for the great range in student aptitude as to offer after all these years but one introductory course in engineering mathematics and physics.

The distinctive general feature of the functional engineering courses should be the separate provision for the needs of men of superior aptitude and for those of moderate aptitude by profoundly technical and moderately technical treatments of the different branches of science, particularly of the introductory mathematics and physics of the first two years.

Distinctive Features of Each of the Functional Engineering Courses, and the Conditions Attending the Transfer from One Course to Another

If the proposals of the last section are well founded, it would seem that the guiding consideration in laying out the courses would not be the thought that the student cannot be certain that he has elected the proper course, and cannot be wisely directed during the first half of his college career, and that the courses should, therefore, be identical in content for as many years as possible to facilitate the transfer from one course to another. Rather, the consideration would be that the courses should be adapted to the aptitudes of the students, and should, therefore, differ from the very beginning, in content and in aim. Facility of transfer in the sense of bookkeeping facility in satisfying rigid graduation requirements should be a minor consideration.

A proposal as to the studies of the first two years is contained in the following schedule.

PROPOSED SCHEDULE FOR FUNCTIONAL COURSES

FRESHMAN YEAR

	1st Semester	2nd Semester
Alg., Trig., and Anal. Geom.**	5 cr.	5. cr.
Chemistry**	4 "	4 "
Mechanical Drawing*	3 "	3 "
English*	3 "	3 "
Human Progress	3 "	3 "
Total	18 cr.	18 cr.

SOPHOMORE YEAR

	1st Semester	2nd Semester
Calculus**	4 cr.	4 cr.
Physics**	5 "	5 "
Non-professional electives	4 "	4 "
Varies from course to course**	5 "	5 "
Total	18 cr.	18 cr.

In those studies marked with a single asterisk, the treatment would be of the moderately technical type. In those studies marked with the double asterisks, the profoundly technical and the moderately technical types of treatment would be available, and the profoundly technical type would be specified in certain courses. For example, the profoundly technical type of treatment in chemistry and physics would undoubtedly be specified for all men enrolled in engineering research. The moderately technical treatment of mathematics would be accepted for men enrolled in engineering supervision, but these men, or any man, would be perfectly free to enroll for the profoundly technical mathematics, *provided* only that he displays superior aptitude for and interest in the study. In those studies not marked with an asterisk, the nontechnical type of treatment might well be acceptable.

By the study entitled "Human Progress" scheduled for the first year is meant an initiatory course for freshman, the features of which are being evolved at a number of universities.* This course goes by such names as, or contains such topics as, "College Aims," "Introduction to Contemporary Civilization," "Introduction to Reflective Thinking," etc. The nonprofessional elective studies of the sophomore year are to be elected from the languages, literature, history, philosophy, psychology, economics, sociology, biology, or political science.

*See "The report of the Committee on Initiatory Courses for freshman," *Bulletin Am. Assoc. of Univ. Prof.*, Oct. 1922.

It will be seen that there are no insurmountable barriers between the proposed courses during the first two years. For example, a man who for two years has been content with the moderately technical treatment of mathematics and physics and who then undergoes a new birth may transfer to the course in engineering research, *provided* he has done thorough work in the moderately technical treatments and is ready and able to pay the price in effort.

In the third and fourth years, the courses would differ more and more. Perhaps a common requirement of all courses should be three or four credits each semester of elective studies from the non-professional group listed above. The feature of the research course would be the requirement of the profoundly professional introduction to a number of branches of physical science. There would undoubtedly be free electives in the fourth year which would permit a man to concentrate in the field to his liking. The engineering management course would be at the other end of the line from engineering research, in that it would accept the non-technical treatment of the physical science and manufacturing arts studies to a greater extent than any other course, and it would require more studies than any other course along business and sociological lines. As regards the moderately technical type of treatment, the engineering sales course would be between engineering supervision and engineering management. In the latter half of the third year students in engineering supervision would undoubtedly start to major, choosing between manufacture, construction, and operation.

Student Counsel and the Determination of Aptitude

This proposal for courses entitled engineering research, design, management, etc., will be criticized on the ground that it is impossible for the student or his counselors to determine, in a period short of a year or more, in which of the courses the student should enroll. It seems to me that the problem with which the student and his counselors are confronted is far simpler than this. The first question to be answered is this: Has the student the aptitude for the type of engineering work which can be prepared for to advantage in a college? If this is affirmatively answered, the questions to be answered for the first year are as follows: Is the student's aptitude for and interest in Algebra, or Calculus, or Chemistry, or Physics, such that he should take the profoundly technical or the moderately technical course in the subject in question?

The answers to the first of the above questions may now be had in no very uncertain terms within two weeks of the opening of the school year. For example, all freshmen engineers at Wisconsin are given a two weeks review in algebra followed by an examination. Students who fail to pass this examination are placed for a semester in sub-freshman algebra. From 25 to 35 per cent of the students in the entering class are required to take this sub-freshman algebra. Of this sub-freshman group, about 45 per cent drop out by the end of the first year, and the percentage qualifying for the degree is quite low.

There is no question but that carefully devised and interpreted entrance examinations and tests will indicate with great certainty a large group of applicants who would be clearly out of place in an engineering college. At the present time, however, the State Colleges, by reason of their relations in the state, cannot reject graduates of the accredited schools of the state on the basis of an entrance examination alone, but must give these graduates a trial. Under these conditions would it not be a very constructive measure to require all prospective engineering students to report at the College one month before the opening of the school year for *engineering counsel*?

During the month of counsel, the prospective engineering students would work for five or six hours per day in computing rooms and laboratories on carefully devised arithmetical, geometrical, algebraic, and physical problems. The work would be carried on under the observation of mature and experienced engineering counselors in classes so small that the counselor would be able to follow the mental processes of each student. The counselors would be the more experienced men from the departments of mechanics, physics, structural engineering, thermodynamics, metallurgy, electrical engineering, etc. At the end of the month of counsel, it would be possible to counsel 20 per cent of the applicants in quite positive terms, and for quite specific reasons, to enter upon some line of work other than engineering. If none of this group were to accept counsel, and if all were to enter the engineering college, over 75 per cent, in my opinion, would drop out during the first year, and not over 2 per cent would go the four years. Another 10 to 20 per cent could be counseled for specific reasons but in less positive terms not to enter the engineering college.

Of the applicants who are judged to have the aptitude for effective work along engineering lines, 15 per cent could be counseled to enroll in the profoundly technical courses in mathematics and physics, and 70 per cent could be *required* to enroll in the moderately technical courses in these subjects.

Counsel rendered in this manner would, in all probability, be far more effective, and would be accepted more readily, or at least with better grace, before enrollment and patent failure than is the advice or the requirement to withdraw after a semester of work. Such a system of counsel has the possibility, not immediately but after a period of trial, of diverting 25 per cent of the applicants from the college of engineering to lines of work in which a more effective and happier future might be expected.

Conclusions

The issue raised in this paper will be clouded if the ground of criticism is that the names engineering research, design, management, etc., are misleading and unwarranted, because it is impossible to teach research, design, or management in a college. A criticism of this type indicates a grave misunderstanding of the aims and claims of educational work. The growth of the individual is never a symmetrical expansion. Growth has direction, and the aim and the claim of engineering education should be to lay the best foundation for the type of work in which the boy seems to have an interest, and for which he seems to have the aptitude. There is no claim that a student who has taken a four or a five year course in engineering design, and who may, perchance, have been granted the degree, B. S. in Engineering Design, is a full-fledged design engineer. But there is, or there should be, a claim to the recognition of aptitude and the development of talent.

It is, perhaps, unnecessary to say that there is nothing magical about the names engineering research, engineering design, etc., as the titles of courses, except that such divisions would facilitate the provision of types of treatment better adapted to the needs of the student groups. That is to say, it would be possible to have courses thus named in which there would be no more administrative provision for the recognition of aptitude than in the existing industrially aimed courses. The important thing is the provision of the profoundly technical and the moderately technical types of treatment. This provision can be made within the existing courses. As an illustration, while it would be simpler to lay out a course in Engineering Research, Electrical Option, provision can be made for an identical course (a course in Electrical Engineering, Research Option) within the existing lines of organization of the Engineering colleges.

This paper is avowedly a plea for the recognition of the necessity for a certain type of specialization in engineering education. If the merits of the proposals are to receive judicial consideration, the indiscriminate use, in educational discussion, of the term *specialization* as a term of condemnation must be abandoned. It must be recognized that there are both good and bad aspects to specialization, and that there are kinds of specialization which on the whole are good, and other kinds which are bad. A bad kind of specialization is that typified by an extensive descriptive treatment of detailed matters of engineering practise.

In the ardor of the crusade against the bad kind of specialization, evils in education which happen to have their origin in the conditions which necessitate specialization in the practise of engineering are, in uncritical fashion, attributed to specialization. As a matter of fact, the evils in question arise from the fact that the course of study is not specialized enough. The evil referred to is the inclusion of too many studies in a course of study, or of too much subject matter in each study. The origin of this practise is the desire to give the student a broad preparation for the work of the engineer. It arises from a desire to avoid specialization. Yet the superficial work which results is vaguely attributed to or associated with specialization, whereas the remedy for the superficial work is specialization in the sense of preparing for a specific type of work. To illustrate, a partial remedy for the lack of proficiency among engineering graduates in the application of mathematics to the problems encountered in engineering practise is specialized courses in mathematics,—a profoundly technical course adapted to the needs of the few, and a moderately technical course adapted to the needs of the many. This lack of proficiency is, perhaps, the most striking evidence that the existing courses as at present administered are not intended for,—or at least, do not lend themselves to,—the effective training of engineering specialists.

Rightly conceived and correctly administered, specialization in the sense of encouraging concentration, and mastery, and leadership through achievement, in some field of activity, is a remedy for, rather than a cause of, superficial habits of thought. If it is feared that leadership achieved in this manner will be accompanied by narrowness of vision, the question may well be raised as to which is the more important to clearness and trustworthiness of vision. Is it the type of insight which is gained in broad surveys of general outlines, or is it the insight which comes from the discipline necessary to the achievement of mastery in narrower fields?

MORE LIGHT, MORE EGGS

It is an axiom in the poultry world that the hen that produces eggs during the months of November to April inclusive is the profitable hen, this representing the period when fresh eggs are at peak prices. It has also been officially established by tests extending over a period of years that no one single factor contributes to winter egg production with the potency of artificial lighting. In official tests conducted in state and federal experimental stations during winter months, it has been conclusively proved that flocks fed and housed identically and cared for in every respect the same have shown spreads in egg production sometimes exceeding 100 per cent in favor of the flocks kept under artificial lights.

Installing artificial lights in city poultrymen's yards is very simple and only involves the purchase of ordinary lamps and wiring to stations. Repeated tests have proved that increased profits from the flock in three months would pay for the electric light plant and all installation charges on the farm. Many large commerical poultry plants are now equipped with artificial lights and experimental stations have also adopted them in national egg-laying contests.

Design Constants and Measuring Units

BY LAWRENCE E. WIDMARK
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Review of the Subject.—*This paper presents a generalization of a method described in a previous paper by the author ("An Arrangement of the Circle Diagram" JOURNAL of the A. I. E. E., September 1922). The author suggests an interdependence between measuring units and the design constants of a machine and employing this method proceeds to outline:*

1. The "unit parabola diagram" for d-c. machine.
2. The "unit circle" arrangement of the Behrend circle diagram.
3. The "C. S. U." (cross-section unit) reference system where length dimensions take the place of ordinary electric units in recording the electrical data of a machine.

The mathematical treatment of the subject should only be considered as giving an idea of the author's intentions and not as an exhaustive mathematical survey of the possibilities and limitations of the method.

* * * * *

THE performance of a machine is, so to say, measured and weighed on the curve sheet. Ordinarily, the unit of the cross-section paper corresponding to one ampere, one watt, or whatever the case may be, is chosen altogether arbitrarily. The only considerations are (1) to get the highest precision possible on a standard sized paper, and (2) to use an even ratio between the units of the cross-section paper and the physical unit in question.

There is, however, another condition which could be imposed on performance curves to a great advantage, *viz: the choosing of the measuring units so as to standardize the curve-shape.*

In other words, we may be able to "freeze" the shape of a function into a fixed curve; have this shape filed in the form of a template and effect the plotting of our performance by using the filed template in connection with straight line construction, if necessary.

This can be accomplished by using a coordinate system, the measuring units of which are suitable functions of some design constant of the machine. Suppose we have a function of the form:

$$A\,X^m + B\,X^n + C\,X + D = E\,Y$$

putting

$$X = \alpha\,x$$
$$Y = \beta\,y$$

we get

$$A/E\,(\alpha\,x)^m + B/E\,\alpha\,x)^n + C/E\,(\alpha\,x) + D/E = (\beta\,y).$$

We can always choose α and β so that

$A/E\alpha^m = B/E\alpha^n = \beta$ and thereby transform the original curve to

$$x^m + x^n + (C/\beta\,E)\,x + D/\beta\,E = y$$

This curve may be considered the sum of

a. the "template curve" $x^m + x^n = y$

b. a straight line.

The load performance curves of electrical machinery are, for all practical purposes, of such a type that it is always possible to perform a favorable unit transformation.

Let us, for instance, take the case of the load performance of a constant speed direct current motor. (see Fig. 1). Neglecting as a first generalization the constant losses, the output curve is a parabola when the input is a straight line. We can now effect the desired *invariance* by using a function of the *resistance* for our measuring units.

Referring to Fig. 1 (upper half), we see that expressing the ordinates, or power values, by using the relation

$$\frac{(\text{volts})^2}{4\ \text{resistance}} = C \text{ ordinate units}$$

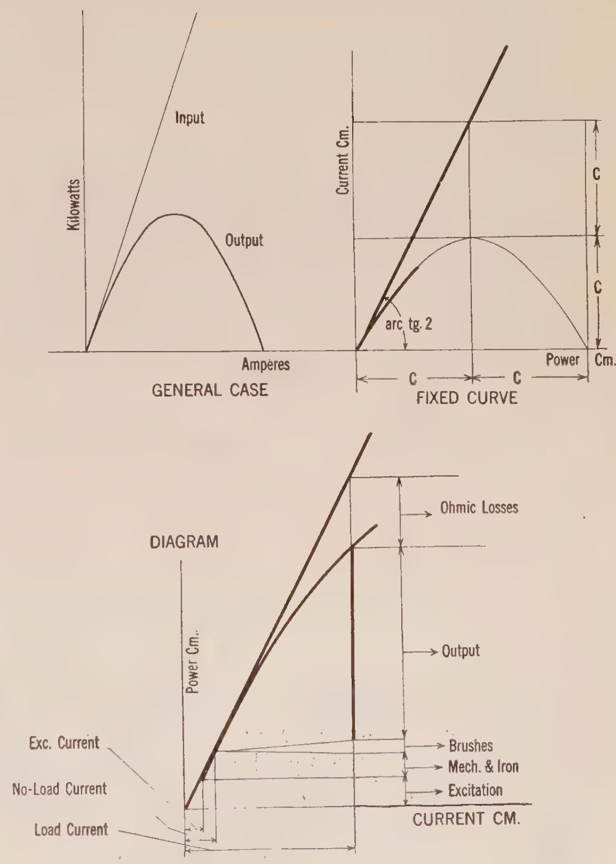

FIG. 1

and the abscissa, or current values, by the relation

$$\frac{\text{volts}}{2\ \text{resistance}} = C \text{ abscissa units}$$

we shall obtain a standard parabola for the output curve and a straight line at an angle of *arc tg 2* for the input line.

The heavily drawn section is the part of the curve

which is useful for ordinary loads and by using a template for it, the performance diagram is easily drawn.

With the suggestions made above, the actual diagram as shown on Fig. 1 (lower half) is self-explanatory and the interested reader will easily find the construction details.

For alternating-current machinery, the *reactance* will be the foundation of our measuring units. The conception now leads to the following interesting results as far as induction motors are concerned.

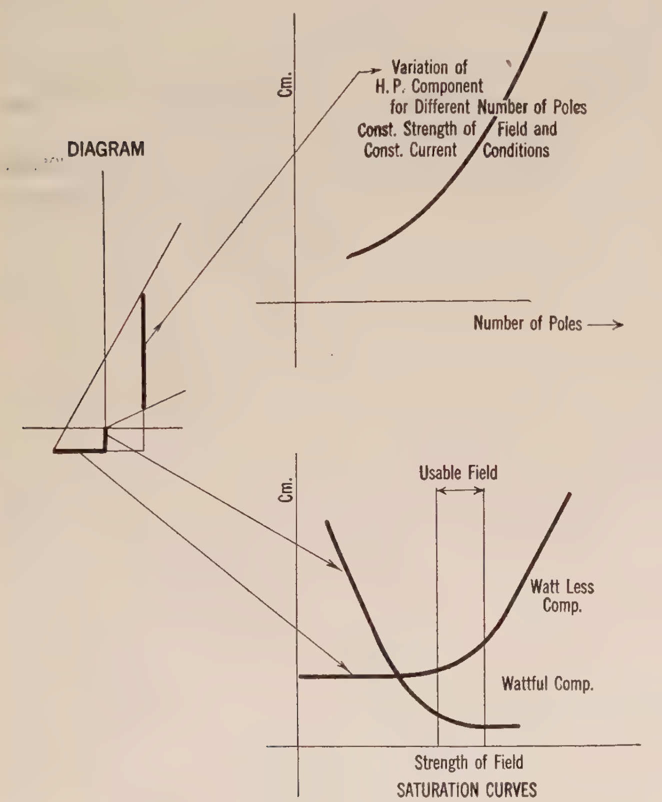

FIG. 2

1. It is possible to determine the measuring unit so that the locus circle of the circle diagram stays *constant* for all machines, small or large, and for different specifications.

2. The effect on power factor, efficiency, torque, etc., by changed winding data may be easily studied on the diagram without disturbing the general geometrical construction just by a *simple movement of the horse power component and no-load line.*

3. The use of the diagram length of the horse power component for a certain strength of field gives a far more manageable and generally useful measure of the *electric capability* of the machine than reactance information given by ohms, henrys or amperes.

Actual values of the length of the horse power components are plotted logarithmically against a varying number of poles on Fig. 3.

4. It is possible to build up an entirely new system of recording *exciting current and wattful no-load current,* far more illuminating and convenient than the ordinary saturation curve. Furthermore, it is independent of volts and (practically) phases. This is done by plotting the length of the aforesaid currents as they appear on the diagram at varying strength of the field.

Examining the saturation curves, (lower left hand corner of Fig. 2) attention is invited to the fact that the method shows very strikingly how the design is confined to a narrow margin of variation of the strength of the field by the rise on one side of the relative no-load losses and on the other side by the relative size of the exciting current.

Concerning paragraphs marked 1 and 2, refer to the author's paper "An Arrangement of the Circle Diagram" JOURNAL of A. I. E. E., September 1922, whereas Fig. 2 illustrates the possibilities of the features described in paragraphs 3 and 4.

The method described above has in practise shown its great advantage, and if proper records are kept in accordance with paragraphs 3 and 4, the design for any induction motor application is arrived at almost instantly. At the same time, we have a tell-tale picture of its different aspects.

Furthermore, if a firm once has standardized on a

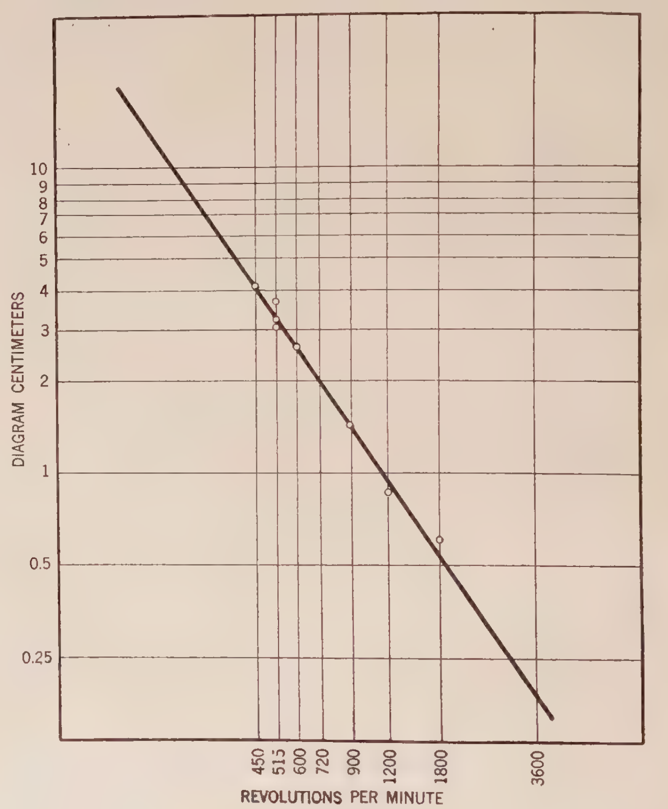

FIG. 3

Diagram cm. per h. p. at varying number of poles, ϕ_0 = 60-cycles, 25 at rated voltage. Tests at ½ rated voltage.

certain relation between design constants and units, we may, for instance, give the following information about a machine: Load component 12½ cm. exciting current 8 cm. no-load watts 2 cm., angle of loss line 0.8 and thereby form a most complete mental picture of the machine in question to any one initiated in the system.

It is thus apparent that the system can be used even without direct connection with a diagram.

Transmission Line Transients*

BY V. BUSH

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THE purpose of this paper is to present briefly the results of an investigation on transmission line transients recently performed in the Department of Electrical Engineering, Mass. Inst. of Tech., by Messrs. S. M. Jones, J. A. Scott, B. Van Ness, and D. C. Jackson, Jr., graduate students in the department. The object of the research was to check experimentally part of the theory of transients on transmission lines and cables, and to investigate qualitatively certain phenomena of reflection and wave form.

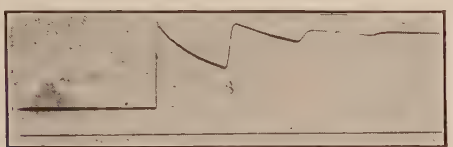

Fig. 1

The present research was made possible by the development of a smooth artificial transmission line which is described in an accompanying paper by Prof. F. S. Dellenbaugh, Jr. Laboratory work was also supplemented by tests in the field on the Georgia-Alabama tie line, performed during the past summer by Prof. Dellenbaugh and Mr. Jones. This line was made available through the courtesy of the Georgia Ry. & Power Co. and the Alabama Power Co.

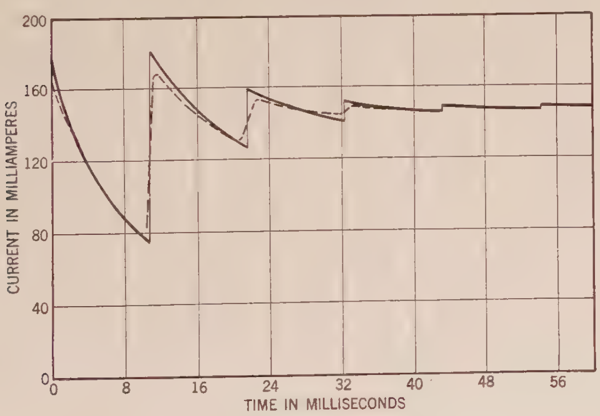

Fig. 2

All tests were made by suddenly applying or removing steady or continuous potentials. The results however, apply to most cases of the application of alternating potentials, for ordinarily the initial waves of voltage and current have become much attenuated before great change has occurred in an applied potential of commercial frequency.

*Abridgement of a paper presented at the A. I. E. E. Annual Convention, Swampscott, Mass., June 28, 1923. Complete paper available without charge to members on request.

In Fig. 1 is shown the current entering a smooth artificial line with the distant end short-circuited, and a steady voltage suddenly applied at the home end.

The transients were computed principally from Heaviside's and Carson's formulas, with Mr. Carson's

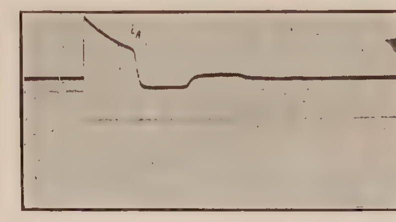

Fig. 3

much appreciated assistance in interpretation of difficult points in connection with some of the later work.

In Fig. 2 is plotted the computed curve, by the full line, for the above case. On this same diagram is plotted, dotted, a copy of the oscillogram. The

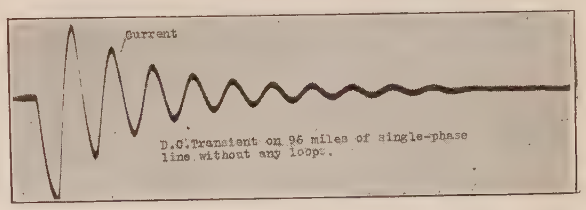

Fig. 4

correspondence is seen to be excellent except immediately at the wave front.

These measurements may be considered a check upon theory as far as the amount and nature of reflections and the wave shape except at the wave front are concerned.

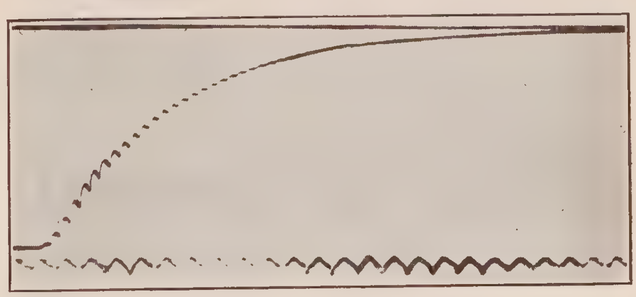

Fig. 5

The oscillogram of Fig. 3 gives the home end entering current for a suddenly applied constant voltage when the distant end of the 990-mile (1612 km.) line is open. In this case the current reverses in sign, and flows alternately into and out of the line, subsiding to a

steady value of zero current since the leakage is negligible.

In Fig. 4 is shown the current for an artificial line only 96 miles (156 km.) long with the distant end open. Here the reflections follow so rapidly that the curvature

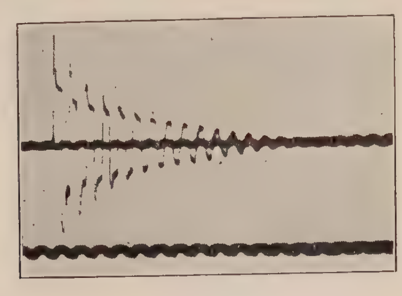

Fig. 6

of wave front soon masks the theoretically sharp cornered form.

Oscillograms for comparison taken on the Gadsden-Lindale tie line are shown in Figs. 5, 6 and 7. The first was taken with the distant end grounded, and the others with it open.

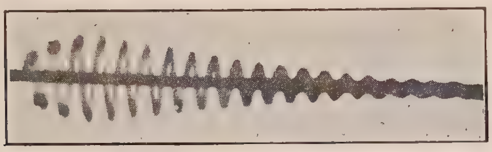

Fig. 7

Computations again showed these curves to agree with theory as well as could be expected in view of the experimental difficulties involved; Fig. 8 shows a computed curve superposed on the beginning of one of the enlarged oscillograms.

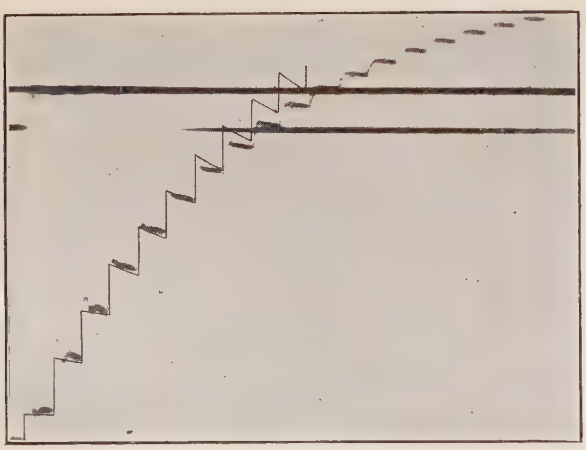

Fig. 8

Neither the artificial line nor the actual line of practise corresponds exactly to the ideal line which is mathematically analyzed. This ideal line is considered to have four constants which are absolutely fixed, and which are the same at every point of the line. Hence it is to be expected that there will be a departure of experimental results from those indicated by this basic theory. No case in which these simplifying assumptions are not made has ever been completely analyzed mathematically.

Our experimental results indicate, except for the peculiar initial departure noted above, that the actual progress of waves in practise follows that predicted by theory except at the wave front. Simple theory indicates wave fronts that diminish in height but remain strictly perpendicular. The wave fronts of practise are rounded off.

The physical aerial line departs from the simple case assumed in analysis in the following particulars:

1. *Skin Effect.* 2. *Ground Effect.* 3. *Radiation from the Line.* 4. *Periodicity in the Line.* 5. *Corona.*

For transients on power cables there is an additional modifying factor: 6. *Effect of Solid Dielectric.*

It is hence not yet possible for the artificial line to yield complete information regarding the steepness of wave front to be found on physical lines. In other respects it gives reasonably accurate duplication, and its use will probably increase for the study of all kinds of transients upon networks which are too complicated for mathematical analysis. It is of importance to inquire how important in practise is this matter of steepness of wave front, which cannot be either experimentally or theoretically determined at present.

During the system transient characterized by traveling waves we are interested primarily in the abnormal voltages which may appear at various parts of the network, their duration and the number of times theyre a repeated. Later, during the second class of transient, when machine constants enter as a controlling factor, we are principally interested in abnormal currents, and in the mechanical stresses and the switch duty thereby imposed. During the first part of the disturbance following a switching operation, however, we are interested in waves of current only in so far as they may result in abnormal voltages.

Much has been written about steepness of wave front, and an exaggerated idea of its importance has as a result been popularly produced. We need consider the steepness of a wave only as it affects the voltages produced by the wave. Steepness of wave front even of a current wave can in itself produce no harm.

The transformer is the usual terminal apparatus on physical lines. This is a system with decidedly distributed constants, containing capacity both between turns and to ground. The impact of an incoming wave of voltage over a line upon a terminal transformer is in the first instant exactly equivalent to the sudden application to the terminal or terminals by any other means of the same voltage as that produced by the incoming wave. By the first instant, in this connection, is meant the time during which the transformer transient is determined by its capacity between coils and to ground, and before appreciable

current has begun to flow in the windings. It is during this period that the maximum potentials ordinarily occur. It makes little difference in the effect produced whether the voltage thus suddenly applied grows to its maximum value in one or one hundred microseconds. The worst case that can happen for a given maximum voltage, is to apply it directly and suddenly to the transformer terminals without an intervening line. The effect of the line on the wave front can be only in one direction, namely to decrease slightly the suddenness of application. As far as voltage waves are concerned, therefore, we have nothing to fear on account of steepness even when the strictly perpendicular wave front impinges upon a terminal transformer.

The presence of a long transmission line may indeed have an important influence in connection with the effect produced on terminal apparatus during switching, but this influence is usually entirely apart from any question of the steepness of wave front. When a continuous voltage, E say, is suddenly applied directly from a generator to a pair of transformer terminals, the voltage across the terminals very rapidly arrives at the value E and stays there. Due to the inductance of the source and the distributed electrostatic capacity of the transformer, the terminal voltage will, in fact, rise instantaneously to nearly double, and then oscillate about its final value E. The duration of this oscillation is fortunately exceedingly brief, as it is determined by the natural period of a circuit consisting substantially of the inductance of the leads in series with the distributed capacity of the transformer and of the source. Hence in switching a transformer onto a generator, we do not ordinarily have to consider, as far as insulation is concerned, that there is any overvoltage produced at all. It takes time as well as excess voltage to produce a breakdown.

If now, however, a long transmission line be introduced between the source and the terminal transformer, a new condition must be considered. Upon closing the switch a wave of voltage of height E runs down the line. Upon arriving slightly attenuated at the transformer, this wave is reflected in the first instant nearly as though the end of the line were open, for at first the transformer inductance prevents it from drawing appreciable current. The voltage wave is thus reflected and nearly doubled. This doubled voltage then persists across the transformer until the arrival of the next wave, or until the flow of current into the transformer drags it down. We thus have across the transformer terminals an overvoltage which can last for a considerable period, and hence may be capable of producing breakdown. The presence of the line, while it has been able to affect the amount of voltage produced or the suddenness of its application only in a favorable direction, has nevertheless introduced a longer duration of the overvoltage which may be serious.

The voltages produced throughout a piece of terminal apparatus by an incoming wave of voltage may be completely analyzed from a knowledge of the voltage only. Any failure to compute the voltage produced at any point will be due to lack of analytical ability, and not to deficiency of premises. The system is completely fixed once the constants of the apparatus and of the line, and the amount of voltage, are given. The wave of voltage is accompanied by a wave of current. Can this wave of current, penetrating the apparatus, produce disastrous effects? Obviously it can produce only those voltages which have already been found from an analysis of the effect of the voltage wave. We are interested in overvoltages. Hence if we will completely treat the effect of an incoming wave of voltage, we can forget about the accompanying wave of current, knowing that we have completely taken it into account.

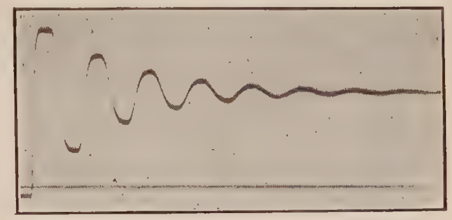

Fig. 9

It follows, therefore, that the steep wave front of current is entirely innocuous, in any case where the sudden application of the corresponding voltage does no harm. This may seem strange, for the impact of a perpendicular wave of current on a piece of highly inductive terminal apparatus looks dangerous offhand; but reflection will show that the danger is very likely to be entirely visionary.

A wave of voltage arriving at the open end of a line is entirely reflected without change of sign, and hence completely doubles. The end of the line experiences momentarily a maximum voltage of twice the value of the incoming wave. This maximum voltage is altered after the first instant by attenuation and change of wave form.

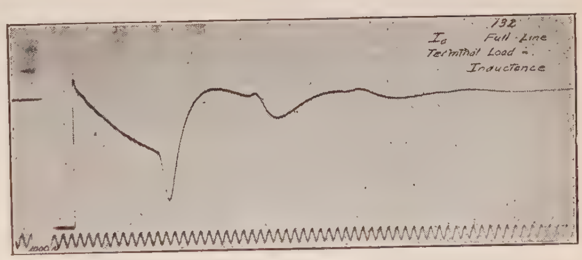

Fig. 10

This is illustrated in Fig. 9, which is an oscillogram of voltage at the distant end of an open artificial line of length 330 miles (537 km.).

A wave impinging upon a lumped inductance devoid of distributed capacity will be in the first instant completely reflected.

In the oscillogram of Fig. 10, taken on a line with an inductance load, this effect is clearly shown. The curve is of current at the home end.

When a line is opened, by a switch or by a wire breaking, the current is suddenly decreased at that point from the previous value I to zero. A wave of current, a depression in this case, then runs over the line

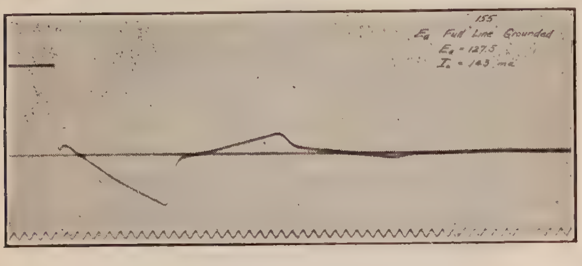

Fig. 11

and reduces the current to zero on the line as it goes. This wave of current is accompanied by a wave of voltage.

This is shown in Fig. 11 and Fig. 12. In the former, taken on the full length of the line, and interrupting short-circuit current, the voltage at the break remains positive, but nearly zero. In the latter, using one-third the length of line, the current is three times as

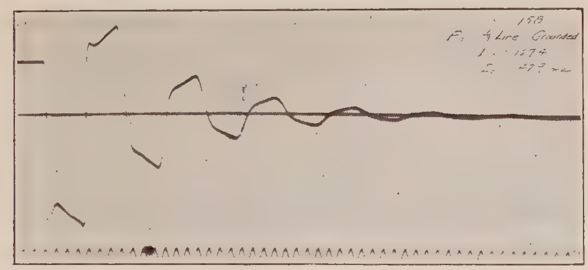

Fig. 12

great so that the voltage rises to nearly twice E negative.

The maximum voltage on breaking a circuit need not appear at the point of breaking. The voltage wave running over the line may be nearly doubled at an open end or a transformer winding.

A special case may occur when a line, terminating in a transformer at the distant end and carrying a heavy

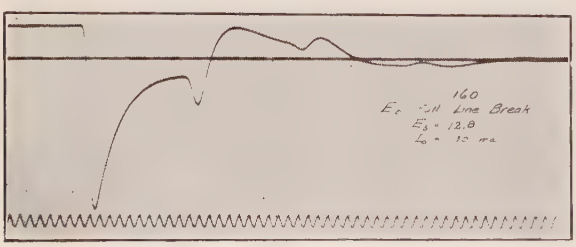

Fig. 13

current, is suddenly interrupted at the near end. In this case the wave of voltage running over the line is reflected without change of sign at each end, and hence builds up continuously, and to a large extent, particularly if the line is short in length. Some of these cases have been discussed by Wagner.

An oscillogram for this last condition is shown in Fig. 13.

STANDARDIZATION OF ELECTRIC POWER IN AUSTRALIA

CONSUL NORMAN L. ANDERSON, MELBOURNE

Australia has lagged behind other countries in electrical development, and what has been done there has been accomplished without any comprehensive plan. The only States where attempts toward coordination have been made are Victoria and Tasmania. At a conference between Commonwealth and State ministers, held in Melbourne in May, 1923, it was, therefore, proposed that steps should be taken without delay to form a central controlling body, coordinating the action of State and Federal Governments. It was further suggested that steps should be taken at once to form a committee representative of the States and of the Commonwealth with technical advisers on the lines of the British electricity commission. An outline of the investigations proposed follows:

1. Determine the immediate prospective power needs for Australia for the next 20 years;
2. Make an inventory of the resources, both of fuel and of water power, available to supply the demand;
3. Make preparation of the general lines of a comprehensive power scheme for the whole of Australia, showing the sites of the suggested power stations, and laying down standards to be observed in the generation, etc., in all installations wherever situated, such standards to be enforced by legislation in all the States;
4. Determine the order in which the various units of such a comprehensive scheme should be developed;
5. Formulate an agreement as to the share the Commonwealth should bear of the cost of preparation of the completed plan and the installation of the individual units, especially the border units of such national power scheme;
6. Estimate the value of such a scheme from the point of view of immigration, and outline the proper methods of construction and of securing loans for the schemes when constructed.—*Commerce Reports.*

ELECTRICITY GENERATED IN GREAT BRITAIN

According to a pamphlet entitled "Generation of Electricity in Great Britain," 5,738,718,485 kilowatt hours of electrical energy were generated during the year ended March 31, 1923. The amount of the previous year was reported as 4,884,666,039 kilowatt hours. The data were compiled by the British electricity commission. Coal consumption per kilowatt hour in steam plants, which generated more than 95 per cent of the total, averaged 2.78 pounds, as compared with 3.11 pounds during the period ended March 31, 1922. Eight plants are dependent entirely upon water as a source of power, while 19 others rely partially on this source.—*Commerce Reports.*

Telephone Equipment for Long Cable Circuits*

BY CHARLES S. DEMAREST

Member, A. I. E. E.

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Review of the Subject.—*Some of the important developments contemplated in the apparatus and equipment for long toll cable circuits are described. The large number of equipment units per station in the cable plant and the greater number of stations in a given length of cable than in an open-wire system, have made the economic importance of the equipment design such that a comprehensive program of development, affecting many types of equipment, has been undertaken. The outstanding features of some of the more important of these, including the telephone repeater equipment, test board equipment, and signaling equipment, are described. The necessity for compactness in the dimensions of equipment units, uniformity in assembly arangements, and simplicity in design, together with the need of careful correlation of the electrical and mechanical requirements, are emphasized. The methods proposed for meeting these requirements generally, are described.*

* * * * * *

THE construction features and transmission characteristics of long distance telephone cables have already been brought to the attention of the Institute, but the development of suitable apparatus and equipment for these cables has not yet been discussed. It is the purpose of this paper to present, briefly, a picture of what is being accomplished in this development work.

A cable system requires a greater number of repeater stations in a given length of line than an open-wire system. This is because of the much smaller gage conductors which the cable employs and the closer proximity to each other of these conductors. Consequently, in a cable system, more of the plant investment is represented by the equipment within the repeater stations than is the case with open-wire construction. Furthermore, the number of equipment units per station in a cable system is ordinarily much larger than in the open-wire plant. This is due to the fact that the use of long cable circuits has been desirable chiefly on routes carrying heavy traffic where many circuits are needed. Thus, the requirements of the cable plant have been such as to emphasize the economic importance of the equipment.

To meet these requirements, it has been necessary to undertake a comprehensive plan of development affecting many types of equipment. The outstanding features of some of the more important of these, including the telephone repeater equipment, test board equipment and signaling equipment are described in the complete paper. It will not be possible to describe many of these developments here, but some idea of what is being done in this connection may be given by a brief account of the progress in telephone repeater development.

The telephone repeater, in its present form, has been the chief factor in making long distance cable telephony practicable. It is probable that the developments in connection with telephone repeaters have been among the most rapid and comprehensive of any in the toll equipment. Furthermore, the design of the telephone repeater, as now conceived, embodies features that may be applied advantageously to much of the other equipment. It will be interesting to note, therefore, the principal steps which have been taken in working out the form of the equipment, in this typical case, to the degree of efficiency required in the cable plant.

Fig. 1 shows one of the original forms of repeaters, a number of which were installed as early as 1914. In this case the repeater apparatus was assembled in boxes designed to mount on the wall, each box containing a one-way amplifier. With this type of design, the balancing networks and miscellaneous

FIG. 1—BOX TYPE REPEATER INSTALLATION

apparatus were mounted on a separate rack with the plate batteries for the vacuum tubes in an adjacent cabinet.

The first vacuum tube telephone repeater adapted to commercial manufacture was of the type shown in Fig. 2. All of the apparatus for a two-way circuit, excepting the batteries, was mounted together on one rack. The testing equipment and signaling apparatus were duplicated in each repeater set and mounted on the same rack as the repeater, together with the balancing networks.

Fig. 3 shows the type of set which was standardized in 1917 for use on open-wire lines. This form of set

**Abridgement of paper presented at the Annual Convention of the A. I. E. E., June 27, 1923. Complete paper available without charge to members on request.*

was a great improvement over the earlier types. It employed, however, much of the large apparatus that

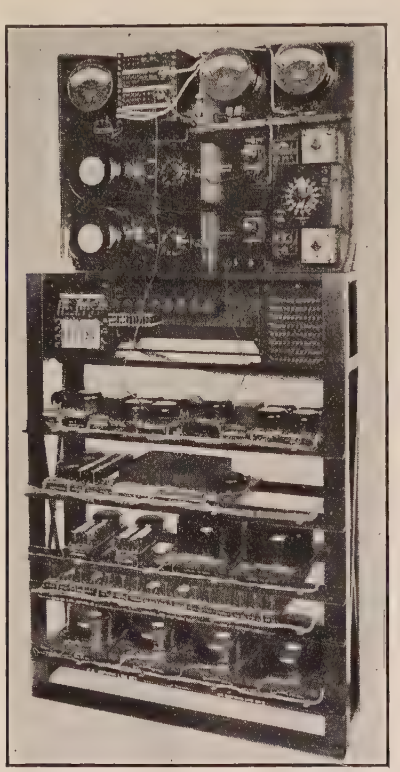

Fig. 2—Wide Rack Through Line Repeater

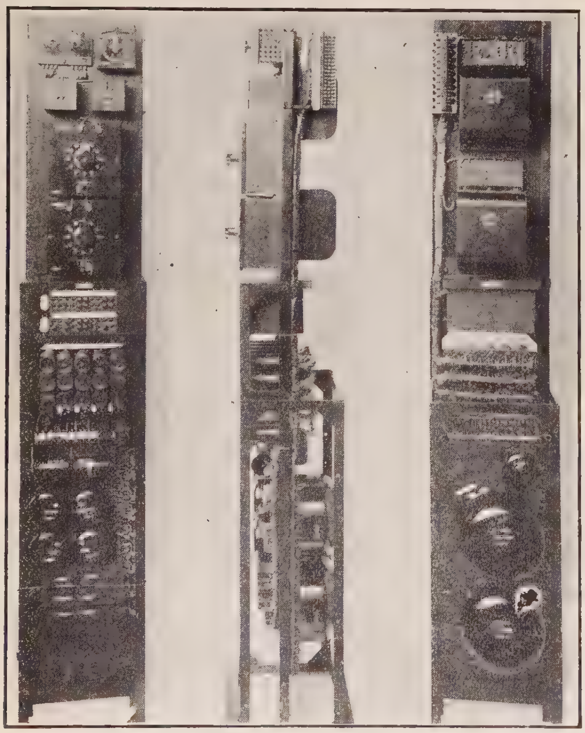

Fig. 3—Standard Through Line Repeater for Open-wire Use

was used in the former sets, and the testing equipment was required to be duplicated for each group of six repeaters. This type of set has been used in many of the smaller installations, but it has not met the requirements for large cable installations.

Fig. 4 represents the type of telephone repeater which is now being developed for all classes of installations employing the two-way, two-element, or "22-type" circuit. The illustration shows the basic repeater unit, divested of accessory apparatus. The apparatus mounted outside of the metal cover on the front of the panel includes all that may ordinarily require adjustment. That which is mounted under the metal covers, both on the front and rear, is such as not to require attention unless wiring changes are to be made.

Some of the principal features of this proposed type of set, which distinguish it from the earlier types of repeaters, are indicated in Fig. 5. Heretofore, certain accessory apparatus which varied in type according to the use of the set, was assembled together with the repeater in one unit. Several types of these repeater units were accordingly necessary to meet the various field conditions. This is to be avoided in the new design by separating from the basic repeater unit such ap-

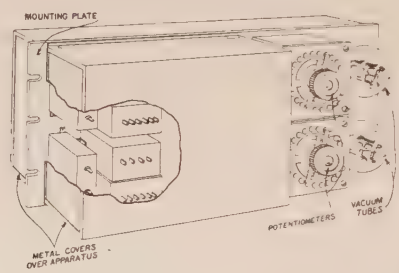

Fig. 4—Typical Assembly of Panel Mounted Repeater Set

paratus as may be required to be different under different conditions of use, or which may be made common to a number of sets.

Fig. 6 shows the general arrangement proposed for assembling a group of sets of the new type in a large cable installation. When mounted in this manner, much saving in space is effected, and average floor area of only 1.5 square feet being required per unit, including allowances for aisle space and associated equipment, as compared with about 15 square feet for the type of set shown in Fig. 1.

The advantages of this method of mounting seem to be such that it is planned to use it for much of the other cable equipment such as testboards and signaling equipment, as well as for the telephone repeaters. It seems desirable, therefore, to mention briefly some of the features of this method which are likely to have general application.

Fig. 7 is a general view showing how the panel assembly method might be applied in any typical case involving a large number of equipment units. The supporting iron work for the panels extends from the floor to the ceiling in order that all of the vertical

space may be utilized. The rear aisles are made narrower than the front aisles, since, as previously mentioned, the apparatus not requiring adjustment is mounted on the rear and less room is needed where the maintenance work is less frequent. Thus, all available space is taken advantage of, to the extent that the floor area required per equipment unit is as small as practicable.

height is in all cases to be a whole multiple of a certain basic dimension. By applying such standard specifications widely, it will be possible to secure interchangeability between panels, as well as to permit uniform methods in grouping the different units.

This outline has been limited chiefly to the assembly and mounting methods, for the sake of brevity. Of course, this is but one phase of the developments in

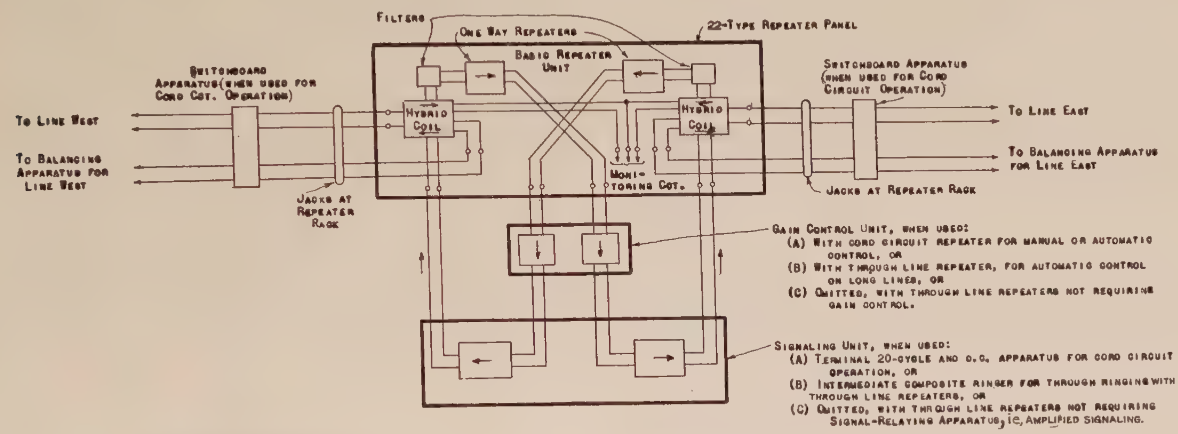

FIG. 5—SCHEMATIC CIRCUIT DIAGRAM SHOWING TWO-WAY TWO-ELEMENT REPEATER ARRANGED TO EMPLOY ONE TYP OF BASIC REPEATER UNIT FOR ALL CLASSES OF SERVICE

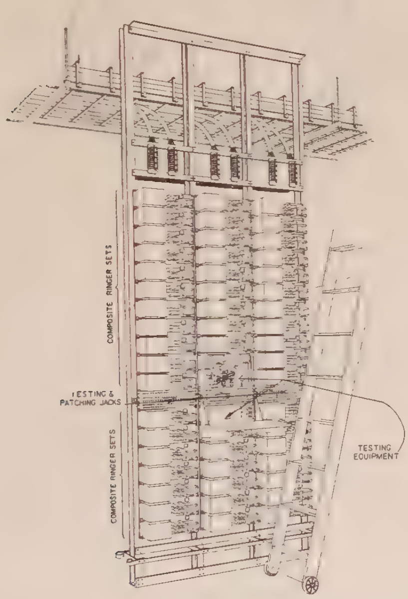

FIG. 6—GROUP OF PANEL MOUNTED REPEATERS AS ARRANGED IN A LARGE INSTALLATION

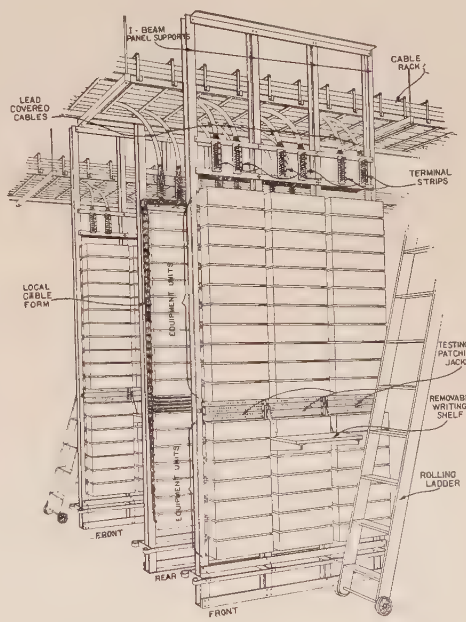

FIG. 7—GENERAL VIEW SHOWING TYPICAL GROUP OF EQUIPMENT UNITS EMPLOYING PANEL MOUNTING METHOD

The need of uniformity in the design of the many different types of equipment units required for the cable plant is also important. This will be accomplished effectively in the new equipment by the standardization of certain dimensions. As far as practicable, all panels are to be of a standard length designed to mount on vertical supports spaced uniformly between centers. The height of the different panels will vary, according to the amount of apparatus in each unit, but this

cable equipment. The improvements in mechanical design are to be coupled with important ones in the electrical circuits and power arrangements, certain of which are described in the complete paper. These electrical and mechanical developments are being very closely coordinated, to insure that both should contribute to the highest degree of efficiency in the functioning of the cable system as a whole.

Polyphase Reaction Synchronous Motors

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THE reaction synchronous motor in its present form (salient-pole rotor without field coils) is one of the oldest types of electric motors, antedating the induction motor by many years. At first it was used only in connection with instruments, such as the oscillograph etc.; later its simplicity and exactness in keeping in step made it the standard driving motor for rectifying devices such as are used for charging low-voltage batteries, supplying high-tension unidirectional current for x-ray and electric precipitation apparatus etc., where the power may amount to several h. p. It is, however, safe to say that the limit of output of the present type is practically reached; its low weight efficiency and poor performance are inadmissible in motors of larger output and seem to justify the general opinion that the reaction motor is inherently inferior to the other types of a-c. motors.

The object of this paper is to develop the theory of the reaction motor; to show that its inferiority is mainly due to the faulty form of the rotor, and to analyze a construction whose performance can be made comparable to that of any standard type of a-c. motors.

For many reasons it can hardly be expected that reaction motors will ever be extensively used; but the comparative simplicity and fairly good operating characteristics of the suggested type should commend its use in cases where a constant speed is either desirable or necessary, but where the amount of power involved does not justify the complication and expense of the standard d-c. excited motor.

Theory of the Polyphase Reaction Motor

Let S (Fig. 1) be a stator magnetically symmetrical in all directions; D and T, sinusoidal current waves displaced 90 deg. and set up by suitable stator windings; R, a rotor without winding, stationary with respect to D and T, having two axes of symmetry corresponding to D and T and magnetically so constituted that the fluxes F_d and F_t set up by D and T respectively are sinusoidal in shape and displaced 90 deg. but the reluctances for F_d and F_t are different and such that, D and T denoting the amplitudes of densities of the current waves, $\frac{F_t}{F_d} = T/D \times k$, with $k<1$. The question how and to what extent such a rotor can be realized in practise will be discussed later. The fields F_d and F_t will be called "direct" and "transverse" respectively

The torque between the stator and rotor is the difference of the actions of F_d on T and F_t on D; it is proportional to $F_d T - F_t D = F_d T (1 - k)$, and is different from zero if $k \neq 1$. An ordinary polyphase winding sets up a current wave whose fundamental term rotates with synchronous speed; if the rotor is brought to synchronism, this fundamental term can be resolved into the components D and T along the axes of the rotor; the combination develops a torque $F_d T (1 - k)$ and constitutes a reaction synchronous motor. The performance is not greatly affected by the non-synchronously rotating higher harmonics of the current wave because the torque due to the action of the synchronously rotating fields F_d and F_t on these harmonics is zero. The fields set up by these harmonics are variable in shape on account of the variable reluctance of the rotor; they are to a great extent suppressed by the squirrel cage with which the rotor is usually provided for starting as induction motor; at synchronous speed the torque action between these fields and the squirrel

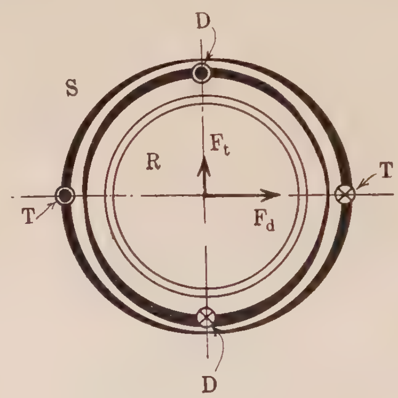

FIG. 1

cage is small and can be neglected, as in the elementary theory of the induction motor.

In Fig. 2, I is the stator current; I_d and I_t are its components setting up the fields F_d and F_t respectively; these fields generate back e. m. fs. E_d and E_t, so that $E_d = X I_d$ and $E_t = k X I_t$, where the exciting reactance X of the direct field is calculated as for an induction motor.

Performance by Circle Diagram. Let r and x be the stator resistance and leakage reactance (slot and end connections) per phase and ψ = phase angle between $-I$ and E_d. In Fig. 3 $O I = I$; the applied voltage $O E'$ is the sum of $O R' = r I$, $R' S' = x I$, $S' M' = E_d$ and $S' N' = E_t$. Let $M' E' C'$ and $N' B' E'$ be drawn parallel to $S' N'$ and $S' M'$ respectively. Since $E_d = X I_d = X I \sin \psi$, and $E_t = k X I_t = k X I \cos \psi$, $S' C' = \frac{E_d}{\sin \psi} = X I$ and $S' B' = \frac{E_t}{\cos \psi} = k X I$; this shows that if the current I

is constant, the points B' and C' are fixed, and E' moves on a circle 1 described on $B' C'$ as diameter. At B' and C' the resultant back e. m. f. is normal to $O I$; the torque is zero; E_d and E_t, *i. e.* I_d and I_t are zero respectively, which means that at B' and C' the axis of the resultant current wave coincides with one of the axes of the rotor.

From the locus 1 of the applied voltage at constant current I the current locus at constant voltage V is derived by inversion with O as center and $V \times I$ as

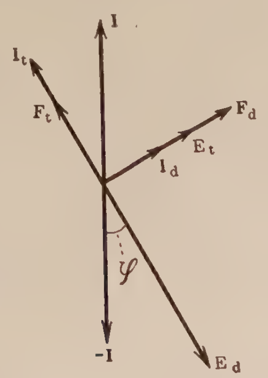

Fig. 2

constant of inversion, followed by a rotation over 180 deg. around $O I$; this gives a circle 2 passing through the zero torque points C and B, corresponding to C' and B'. Since 1 is normal to $R' C'$ the locus 2 is normal to the inverse of $R' C'$, *i. e.* to a circle 3 of radius $\frac{V}{2 r}$, tangent to $O X$ at O ($O X \parallel R' C'$) and having its center O_3 on $O I$. This condition and the points C and B of impedances $(r, x + X)$ and $(r, x + k X)$ respectively determine the locus directly from design data. If the core loss is assumed constant, it can be taken into account by transferring the origin to the point O', below O.

At any point E the torque in synchronous watts is $V \times E K$, where $E K$ is perpendicular to the diameter $C T$; the proof is the same as for an induction motor.* This gives the complete performance of the motor.

Reaction Motor Compared with the Induction Motor. The circle diagram affords a convenient means for a comparison of the reaction motor with the induction motor of the same constants r, x and X†. The comparison of the constant current loci of both motors shows* that these loci (and, therefore, the current loci at constant voltage) are identical if $X I (1 - k) = \frac{X^2}{X + x_2} I$, or $k = \frac{x_2}{X + x_2} = \sim x_2/X$, where x_2 is the secondary leakage reactance of the induction motor. Of course, such a reaction motor, having no rotor copper loss, would be somewhat superior to the induction motor.

Torque. The expression of the torque as a function of the phase angle θ (Fig. 3) between the e. m. f. E_d and the vector $V = O E'$ plays an important part in questions relative to synchronizing, hunting and variation of θ with factors affecting the torque, such as voltage etc.; the latter feature is important in motors driving rectifying and contact-making devices. Projecting the closed line $O R' S' M' E' O$ on E_d and E_t gives:

$$(X + x) I \sin \psi + r I \cos \psi = V \cos \theta \qquad (1)$$
$$r I \sin \psi - (k X + x) I \cos \psi = - V \sin \theta \qquad (2)$$

If the stator has q phases, the torque C of the motor is $q I E_d \cos \psi - q I E_t \sin \psi = q X (1 - k) \times I \sin \psi \times I \cos \psi$ synchronous watts, or, with the values of $I \sin \psi$ and $I \cos \psi$ obtained from (1) and (2), and denoting $X + x$ by a and $k X + x$ by b:

$$C = \frac{q (a - b) V^2}{2 (r^2 + a b)^2} \times 2 (- r \sin \theta + b \cos \theta) (a \sin \theta + r \cos \theta)$$

The product of the last three factors can be written

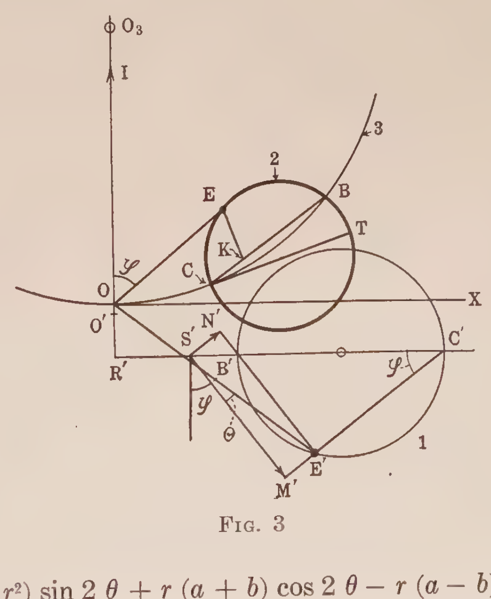

Fig. 3

$(a b - r^2) \sin 2 \theta + r (a + b) \cos 2 \theta - r (a - b)$, which can be transformed into $N \times \sin 2 (\theta - \theta_0) - r (a - b)$, where $N = \sqrt{(r^2 + a b)^2 + r^2 (a - b)^2}$, $N \sin 2 \theta_0 = - r (a + b)$, $N \cos 2 \theta_0 = a b - r^2$. Hence:

$$C = \frac{q (a - b) V^2}{2 (r^2 + a b)^2} [N \sin 2 (\theta - \theta_0) - r (a - b)] \text{ synchronous watts} \qquad (3)$$

C is maximum for $\sin 2 (\theta - \theta_0) = \pm 1$; substitution in (3) gives for C_{max} expressions identical to those

*Journal A. I. E. E., April 1921, p. 326 ff.

†The condition of the same constants r, x and X is approximately satisfied if the stator is the same and the reluctance (air gap, rotor saturation etc.) is adjusted for the same X. The reactance x of the reaction motor, however, has no equivalent of the tooth tip leakage of the induction motor; in the method of calculation of the constant k outlined below, the entire flux in the rotor set up by the rotating fundamental current wave is taken into account for determining the component which sets up back e. m. fs. of fundamental frequency.

derived by a different method in Arnold, *Wechselstromtechnik*, Vol. 14, 2nd ed., p. 230. If $2p$ = no. of poles and $\omega = 2\pi \times$ frequency of the supply, the torque in mechanical units is

$$C = f(\theta) = A \sin 2(\theta - \theta_0) - B \text{ ft. lbs.} \qquad (4)$$

where $$A = 0.37 \frac{q(a-b) V^2 N p}{\omega (r^2 + a b)^2},$$

$$B = 0.37 \frac{q(a-b)^2 V^2 r p}{\omega (r^2 + a b)^2}$$

Performance by Calculation. For a given torque or output expression (3) gives θ; expressions (1) and (2) give I and ψ; the power factor $\cos \varphi$ is then given by the relation $\varphi = \theta + \psi$.

Starting and Synchronizing. Reaction motors are usually provided with a squirrel cage for starting as induction motors. A study of the starting performance would be beyond the scope of this paper; in principle, during the operation as induction motor, a reaction motor is not different from an ordinary synchronous

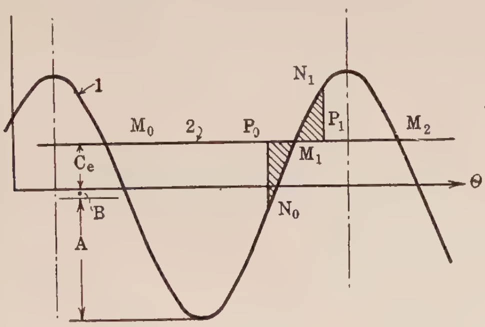

Fig. 4

motor with non-uniform reluctance (salient poles); the difference arises only during synchronizing, which, in a reaction motor, must be accomplished without the aid of the d-c. excitation. For comparison with the d-c. excited motor it is interesting to study the synchronizing under the influence of the synchronous torque alone, the rotor being brought up close to synchronous speed by some external means. If the velocity of the rotor is sufficiently low relative to the synchronism, the torque, considered as a function of the slowly varying angle θ, is approximately given by the expression (4). In Fig. 4, let 1 be the torque $f(\theta)$ and 2 = load torque C_e assumed constant near synchronism. On the arc $M_1 N_1 M_2$ the rotor is accelerated; on $M_0 N_0 M_1$ it is retarded. Let s be the variable slip of the rotor and s_1 its value at the end of retardation, *i. e.* at M_1; the angular velocity of the rotor at M_1 relative to synchronism is $\frac{s_1 \omega}{p}$. If $s_1 > 0$ (under synchronism), θ increases, and the point corresponding to the torque on the curve 1 moves towards M_2. If the velocity is such that the rotor does not reach the synchronism on the arc $M_1 N_1 M_2$, it will not reach it at all, because the work of the retarding forces per period of the curve 1 is greater than that of the accelerating forces. If it reaches the synchronism at a point N_1, it will overshoot it and move with an over-synchronous speed (decreasing θ) back towards M_1. In the assumed absence of any damping effect the rotor will pass M_1 with the initial (but negative) slip and again reach the synchronous speed at a point N_0 corresponding to the same work of $f(\theta) - C_e$ between M_1 and N_0 as between M_1 and N_1 (*i. e.* area $M_1 N_1 P_1$ = area $M_1 N_0 P_0$). Further motion of the rotor will consist in undamped oscillations between N_0 and N_1; in practise they will be damped by eddy currents and the rotor will come to (relative) rest, *i. e.*, fall in step at M_1.

Let θ_1 and θ_2 be the values of θ at M_1 and M_2; the greatest permissible value of s_1 corresponds to the case when N_1 coincides with M_2; it is given by

$$K/2 \left(\frac{s_1 \omega}{p}\right)^2 = \int_{\theta 1}^{\theta 2} [f(\theta) - C_e] \frac{d\theta}{p}, \quad \text{or} \quad s_1^2 = \frac{2p}{\omega^2 K} \int_{\theta 1}^{\theta 2} [f(\theta) - C_e]\, d\theta,$$

where K is the moment of inertia of rotating parts. Substituting for $f(\theta)$ its expression (4) and observing that the condition $f(\theta_1) = f(\theta_2)$ gives $\theta_1 + \theta_2 - 2\theta_0 = \pi/2$:

$$s_1^2 = \frac{2p}{\omega^2 K} \int_{\theta 1}^{\theta 2} [A \sin 2(\theta - \theta_0) - B - C_e]\, d\theta$$

$$= \frac{2p}{\omega^2 K} [A \sin(\theta_2 - \theta_1) - (B + C_e)(\theta_2 - \theta_1)]$$

The torque of a d-c. excited synchronous motor having the same maximum torque is represented by a sinusoidal curve of the same amplitude as 1 (assuming uniform reluctance and neglecting the small constant term analogous to B in (4)); its period, however, is twice as great; the area above the line 2 is twice as great as the area $M_1 N_1 M_2 P_1 M_1$; *i. e.* the d-c. excited motor will pull a given load in step at about 41 per cent greater maximum slip than the reaction motor. This conclusion is also approximately true in the case of the salient pole d-c. excited motor. To sum up, the synchronizing conditions in a reaction motor are not very good; it is always advisable to reduce as much as possible the inertia of the rotating parts; accelerating the rotor beyond the synchronous speed by reconnecting the stator for a lower number of poles may also be considered.

Rotor Structure

It remains now to study the rotor structures embodying special features assumed in the foregoing theory.

This study is obviously equivalent to the determination of the constant k.

In order to increase the torque $F_d\,T - F_t\,D$ for given D and T, it is necessary to prevent, as much as possible, the formation of the transverse field F_t. The usual practise is to cut out that part of the rotor where F_t would be maximum (salient pole or shuttle rotor) but with this construction any reduction of F_t involves some loss of the useful field F_d. With the polar arc sufficiently narrow to give a good torque the weight and performance efficiencies of such a motor are so poor that it can be used only for very small outputs.

A much more effective and logical method of reducing F_t—used in many similar problems—is to divide the rotor into separate sections roughly along the lines of the direct field; with the usual core inductions the gaps between the sections can be made quite wide (Fig. 10) without excessive saturation, so that F_t can be reduced to only a small fraction of its value with an undivided rotor. The polar arc is limited only by mechanical considerations. The mechanical problem of building a rotor without field coils from separate parts is, certainly, not a very difficult one, the more so because the rotor is usually provided with a squirrel cage which can be adapted for this purpose. The method of calculation given below shows that even an imperfect division of the rotor improves the output to such extent that it becomes comparable to that of an induction motor of the same size. To sum up, the divided rotor with a wide polar arc can be considered as the logical form for reaction motors; it remains only

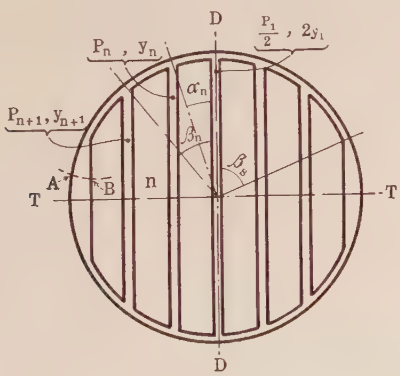

FIG. 5

to investigate how the foregoing general theory can be applied to this construction.

With a rotor of this type the distribution of the fields set up by the sinusoidal waves D and T is not sinusoidal, but consists of the fundamental terms analogous to F_d and F_t of the theory, and of higher terms; the latter are strongly damped by the currents set up by them in the stator windings closed on the source; they can be neglected if their amplitudes are sufficiently small. If Fourier expansion of the field is found, the ratio of the fundamental terms (for $D = T$) gives the constant k; the amplitudes of the higher terms show to what extent the assumption of sinusoidal fields is applicable.

In what follows the sections of the rotor will be assumed to have a shape shown in Fig. 10, *i. e.* leaving only small openings at the periphery; the air gap will be corrected for fringing due to these and slot openings; the saturation of iron will be neglected, the low core densities being both necessary in motors excited by reactive currents and easy to obtain on account of the absence of field coils. With this assumption it is permissible to consider separately the effect of the

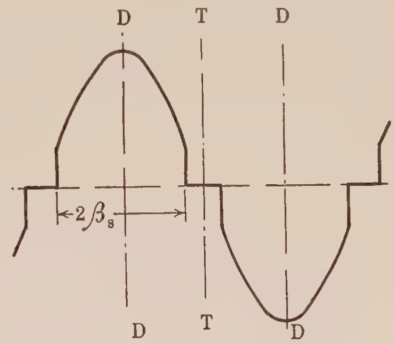

FIG. 6

direct and transverse fields. In Fig. 5 let $2\,s$ be the number of sections per pole (in a rotor without gap along $D - D$ the solid central section is equivalent to two sections in contact), $D - D$ = axis (line of points of zero density) of the wave D, $T - T$ = axis of the wave T, D and T = amplitudes of the waves D and T (in ampere-conductors per unit angle), g = equivalent air gap in cm. = corrected air gap + allowance for iron; x = angular distance of a point from the axis $D - D$, α_n and β_n = angles limiting the nth section; $2\,\beta_s$ = angle of polar arc. At a point x the current densities of the waves D and T are $D \sin x$ and $T \cos x$ respectively. The amplitude of the mth harmonic of a field will be denoted by h_m.

Direct Field. It has the shape of Fig. 6. At a point x (under the pole) the field H_x is $\dfrac{0.4\,\pi}{2\,g}\displaystyle\int_x^{\pi - x} D \sin x\,d\,x$

$$= \frac{0.4\,\pi\,D}{g}\cos x;\ \text{its maximum is } H_{max} = \frac{0.4\,\pi\,D}{g}.$$

Therefore:

$$h_1 = 4/\pi \int_0^{\beta_s} H_{max} \cos^2 x\,d\,x$$

$$= \frac{4\,H_{max}}{\pi}\left[x/2 + \frac{\sin 2\,x}{4}\right]_0^{\beta_s}$$

$$= \frac{0.4\,D}{g}\,(2\,\beta_s + \sin 2\,\beta_s) \qquad (5)$$

and $$h_m = 4/\pi \int_0^{\beta_s} H_{max} \cos x \times \cos m\, x\, d\, x$$

$$= \frac{4\, H_{max}}{\pi\,(m^2 - 1)}\,(m \cos \beta_s \sin m\, \beta_s - \sin \beta_s \cos m\, \beta_s);$$

hence $$\frac{h_1}{H_{max}} = \frac{2\,\beta_s + \sin 2\,\beta_s}{\pi} \text{ and } h_m/h_1$$

$$= \frac{4}{m^2 - 1} \times \frac{m \cos \beta_s \sin m\, \beta_s - \sin \beta_s \cos m\, \beta_s}{2\,\beta_s + \sin 2\,\beta_s}.$$

Fig. 7 gives these two ratios as functions of per cent polar arc; it shows that for the polar arc > 80 per cent the loss of the direct field and the magnitude of harmonics are small.

Transverse Field. The study of the transverse field will be based on the principle often used in similar problems: If the wave T acts alone, the induction in the rotor cores is not great, which means that the *field intensity* H in the cores is very low, and a rotor section has practically the same magnetic potential at all its points, *i. e.* the potential drop is the same along any line crossing the gap between two given sections. If the cores carry a flux due to the direct wave D, there may be some potential drop along this flux, but this drop is not great, and the foregoing assumption is very nearly true, especially in the normal case when there is no excessive difference between the ampere-turns of the wave D consumed in two adjacent sections, *i. e.* when the rates of the potential drop along these sections are approximately the same. The potential drop (ampere-turns) between the sections $n - 1$ and n can be denoted by $y_n\, T$, y_n being a constant. The permeance P_n per cm. axial length of the gap between the sections $n - 1$ and n can be found by sketching an image of the field; it will be considered as known.*

The field H_x at a point x of the nth section is obtained by taking the field integral along a closed path crossing the air gap at points of equal H_x, *i. e.*, symmetrical with respect to $D - D$. It gives

$$2\, H_x\, g = 0.4\, \pi \int_{-x}^{x} T \cos x\, d\, x - 2 \times 0.4\, \pi \times \sum_{u=1}^{u=n} T\, y_u,$$

hence

$$H_x = \frac{0.4\, \pi\, T}{g}\,(\sin x - \sum_1^n y_u) \qquad (6)$$

The unknown constants y can be calculated by writing that the algebraic sum of fluxes entering a section is zero. Let τ = pole pitch in cm.; the flux per cm. axial length entering the nth section by the periphery (both ends) is $2 \int_{\alpha_n}^{\beta_n} H_x \times \tau/\pi\, d\, x = \frac{0.8\, \tau\, T}{g}\,[\cos \alpha_n - \cos \beta_n - (\beta_n - \alpha_n) \sum_1^n y_u]$. The flux entering this section by the sides is $0.4\, \pi\, T\, y_{n+1}\, P_{n+1} - 0.4\, \pi\, T\, y_n\, P_n$ therefore:

$$\frac{0.8\, \tau\, T}{g}\,[\cos \alpha_n - \cos \beta_n - (\beta_n - \alpha_n) \sum_1^n y_u]$$
$$+ 0.4\, \pi\, T\, y_{n+1}\, P_{n+1} - 0.4\, \pi\, T\, y_n\, P_n = 0 \qquad (7)$$

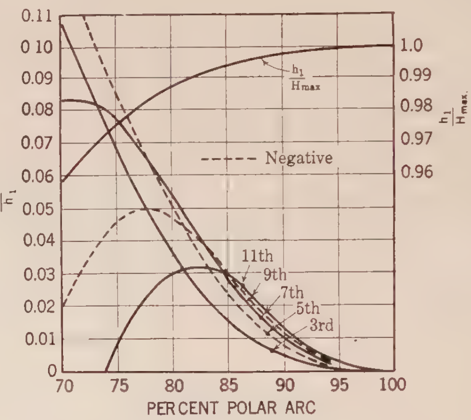

Fig. 7

For the last section the potential difference (a. t.) between the points such as A and B is $1/2 \int_{-x}^{x} T \cos x\, d\, x - \sum_1^s T\, y_u = T\,(\sin x - \sum_1^s y_u)$ and is variable with x;

*Fig. 11 shows a developed pole of the rotor of the type of Fig. 10. The transverse field set up by the wave T consists of lines a crossing some or all the gaps between the sections, and lines b crossing several times the air gap of the motor. As the air gap of a reaction motor need not be greater than in an induction motor, the shape of the transverse field closely resembles the no-load leakage field of the latter; the field a is similar to and of the same order of magnitude, as the slot leakage field (the fact that the slots in question are on the opposite member is immaterial because the wave T is at rest with respect to this member); but the field b is relatively much greater than the tooth-tip field of the induction motor because the rotor surface consists of a few broad teeth, *i. e.*, sections (if the sections themselves have a squirrel cage, it affects the relative strengths of the fields a and b only indirectly, by increasing the reluctance of the equivalent air gap). Or, from a slightly different point of view: the reluctances of the fields a and b are, roughly, in multiple with respect to the m. m. f. T; the former have a large cross-section and a long path in the air; the latter—a smaller cross section and a much shorter path in the air. With a rotor of the type of Fig. 10 the reluctance of the field a is usually much greater than that of the field b.

These general considerations are confirmed by the analytical expressions given below: If eq. (8) is applied to a rotor of this type, it is found that the coefficients A depending on the permeances P are relatively unimportant; therefore, a great accuracy in the assumptions relative to these terms is not necessary. It is also seen that beyond a certain point it is of little use to try to improve the performance by increasing the reluctance of the gaps between the sections; the thing to do is to increase the reluctance of the field b by increasing the number of sections. An obvious consequence of the predominance of the lines b is that the harmonics of the transverse field are very pronounced; but their action on the current wave D is zero because of the difference of periods.

but with a wide polar arc (and there is no advantage in using polar arc $< \sim 80$ per cent) $\sin x$ varies very little and can be given a fixed value; in what follows it will be assumed that $\sin x = \sim \sin \beta_s$; P_{s+1} can then be taken into account simply by correcting the polar arc for fringe; β_s will denote the corrected angle.

Let $P_n \times \frac{\pi g}{2 \tau}$ be denoted by A_n; the eq. (**7**) becomes

$$- A_{n+1} y_{n+1} + (A_n + \beta_n - \alpha_n) y_n + (\beta_n - \alpha_n) \sum_1^{n-1} y_u = \cos \alpha_n - \cos \beta_n \qquad \textbf{(8)}$$

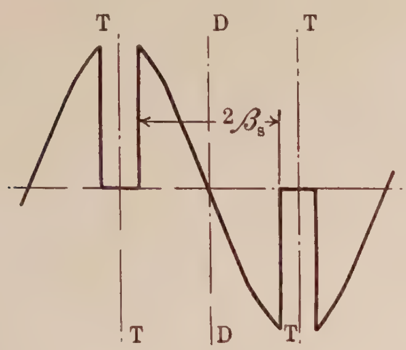

FIG. 8

where $A_{s+1} = 0$ for the last section and $\sum_1^{n-1} y_u = 0$ for $n = 1$. This gives s linear equations to determine the unknown $y_1, y_2, \ldots y_s$; in a rotor without gap along $D - D$, $y_1 = 0$, and no equation is written for $n = 1$.

The expression (**6**) shows that the transverse field is the difference between the field of Fig. 8 and a stepped field in which the step between the sections $n - 1$ and n is $\frac{0.4 \pi T}{g} y_n$. It is convenient to consider this

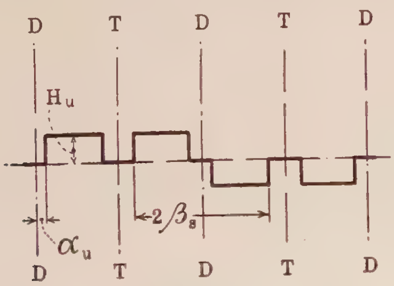

FIG. 9

stepped field as the sum of its horizontal layers, *i. e.*, of s fields of the shape of Fig. 9, in which $H_u = \frac{0.4 \pi T y_u}{g}$. For the field of Fig. 8:

$$h_1 = 4/\pi \int_0^{\beta_s} \frac{0.4 \pi T}{g} \sin^2 x \, d x$$

$$= \frac{0.4 T}{g} (2 \beta_s - \sin 2 \beta_s) \qquad \textbf{(9)}$$

$$h_m = 4/\pi \int_0^{\beta_s} \frac{0.4 \pi T}{g} \sin x \sin m x \, d x$$

$$= \frac{1.6 T}{(m^2 - 1) g} (\sin m \beta_s \cos \beta_s - m \cos m \beta_s \sin \beta_s) \qquad \textbf{(10)}$$

For a field of Fig. 9:

$$h_1 = 4/\pi \int_{\alpha u}^{\beta s} H_u \sin x \, d x$$

$$= \frac{1.6 y_u T}{g} (\cos \alpha_u - \cos \beta_s)$$

$$h_m = 4/\pi \int_{\alpha u}^{\beta s} H_u \sin m x \, d x$$

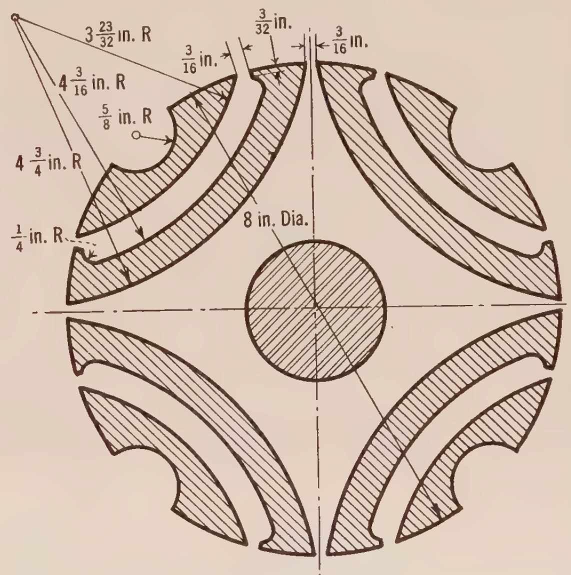

FIG. 10

$$= \frac{1.6 y_u T}{m g} (\cos m \alpha_u - \cos m \beta_s)$$

and for the sum of s fields of Fig. 9:

$$h_1 = \frac{1.6 T}{g} \sum_1^s y_u (\cos \alpha_u - \cos \beta_s) \qquad \textbf{(11)}$$

$$h_m = \frac{1.6 T}{m g} \sum_1^s y_u (\cos m \alpha_u - \cos m \beta_s) \qquad \textbf{(12)}$$

hence, for the resultant transverse field:

$$h_1 = (\textbf{9}) - (\textbf{11}) = \frac{0.4 T}{g} (2 \beta_s - \sin 2 \beta_s) - \frac{1.6 T}{g} \sum_1^s y_u (\cos \alpha_u - \cos \beta_s) \qquad \textbf{(13)}$$

and similar expressions for $h_m = (\textbf{10}) - (\textbf{12})$.

Finally, from (5) and (13) it follows by division (for $D = T$):

$$k = \frac{2\,\beta_s - \sin 2\,\beta_s - 4 \sum_1^s y_u\,(\cos \alpha_u - \cos \beta_s)}{2\,\beta_s + \sin 2\,\beta_s} \qquad (14)$$

The amplitude of the resultant mth term is

$$\sqrt{h_m^2\,(\text{direct}) + h_m^2\,(\text{transverse})}$$

Example. The method is applied to the rotor of Fig. 10 whose constants are: $s = 2$, $\alpha_2 = \beta_1 = 32$ deg.,

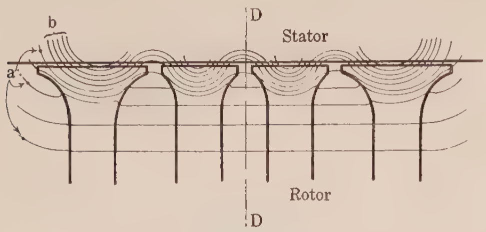

FIG. 11

polar arc $= 2\,\beta_s = 72$ deg. = 80 per cent of pole pitch, $g = 0.021$ in. The rotor cores are proportioned so that, with the max. air gap density = 40,000 per sq. inch the core densities are 75,000 in the section 1 and 93,000 in the narrow part of the section 2. The drawing gives: $A_1 = 0.029$, $A_2 = 0.017$ (with permeances in c. g. s. system), and the equations (8) are $-0.017\,y_2 + (0.029 + 0.558)\,y_1 = 0.152$ and $(0.017 + 0.698)\,y_2 + 0.698\,y_1 = 0.539$; they give $y_1 = 0.273$ and $y_2 = 0.487$; hence, from eq. (14), $k = 0.039$. To compare this motor with an average induction motor having the same stator, it may be assumed for the latter that 0.05 is an average value of the leakage coefficient $\sigma = (x_1 + x_2)/X$; if $x_1 = \sim x_2 = 0.025\,X$, the circle diagram of the reaction motor is the same as that of an induction motor in which $x_2 = \sim k\,X = 0.039\,X$, *i. e.,* $\sigma = 0.025 + 0.039 = 0.064$; the maximum torque of the example reaction motor is about 80 per cent of that of an average induction motor of the same size. With 6 sections per pole it could be further improved, but even with 4 sections it is several times as great as with the salient pole type rotor.

Bibliography

1. E. Arnold, *Wechselstromtechnik*, Vol. 4, 2nd ed., 1913, pp. 228-231.
2. G. Benischke, Drehfeld-Synchronmotoren ohne Gleichstromerregung, *Elektrotechnik und Maschinenbau*, March 3, 1912, pp. 177-180.
3. A. Blondel, Synchronous Motors and Converters, 1913, pp. 141-145.
4. P. Boucherot, Moteur à courant alternatif simple synchrone sans excitation continue, *L'Industrie Electrique*, Vol. 10, pp. 541-542.
5. M. de Coninck, Etude du couple dans les machines synchrones à poles saillants non excitées, *La Lumière Electrique*, April 25, 1914.
6. E. Jasse, Ueber Synchronmotoren ohne Erregung, *Archiv für Elektrotechnik*, 1913, pp. 26-48.
7. Keith D'Alton, The Synchronized Induction Motor, *The Electrical News* (Toronto), October 15, 1919, pp. 39-41 and 44.
8. K. Pichelmayer, Ermittlung der Querfeldspannung bei synchronen Einzelpolmaschinen durch den Versuch, *Elektrotechnik und Maschinenbau*, September 25, 1910, pp. 809-812.
9. Dr. C. P. Steinmetz, Theory and Calculation of Electrical apparatus, 1917, pp. 260-273.

Ambient Temperature Observations

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AMBIENT temperature according to rule 2300 of the A. I. E. E. Standards, "is to be measured by means of several thermometers placed at different points around and half way up the machine at a distance of one to two meters or three to six feet." "The value to be adopted for the ambient temperature during a test, is the mean of the readings of the thermometers (placed as above) taken at equal intervals of time during the last quarter of the duration of the test."

At the suggestion of Professor W. L. Upson,[1] tests were made in the laboratories to check the accuracy of this rule, and, if possible, to suggest a fixed relation between ambient and room temperature in the case of small machines. Two such tests were run; one on a small motor-generator set, and the other on a medium size steam-driven unit.

Test on the Small Unit

The motor-generator set consisted of a 6-kw., d-c. generator, direct-connected to an 8-h. p. motor. The speed was 1175 rev. per min. and the load on the generator was held constant at 150 per cent of rating. The unit was located 50 ft. from one end, and 20 ft. from one side of a room 200 ft. by 60 ft. The room was of an even temperature and free from strong drafts. Ambient temperature was measured by means of 12 thermometers placed level with the shaft, and distributed horizontally as shown in Fig. 1. Room temperature was obtained by averaging the readings of

1. Credit is due Professor Upson for valuable suggestions and criticism, and to H. Schwenk and H. L. Sain for assistance in obtaining the data.

TABLE A

Time	Room Temp.	Thermometer Numbers 1	2	3	4	5	6	7	8	9	10	11	12	Mean
0	27.5	27.6	27.5	27.4	28.6	28.3	28.1	29.4	28.6	28.0	28.0	27.8	27.7	28.1
15 Min.	27.5	27.2	27.2	27.5	28.2	28.6	28.5	29.4	28.3	27.8	27.4	27.6	27.5	27.9
30 Min.	27.5	27.7	27.8	27.3	28.6	28.6	28.6	29.0	28.2	27.8	27.6	27.7	27.8	28.1
45 Min.	27.6	27.7	27.2	27.6	27.8	27.8	27.8	29.4	28.9	28.6	27.8	27.6	27.8	28.0
Mean	27.5	27.6	27.4	27.5	28.3	28.3	28.2	29.3	28.5	28.0	27.7	27.7	27.7	28.0
Mean		27.5			28.3			28.6			27.7			

Mean Ambient − Mean Room = 28.0 − 27.5 = 0.5 deg. cent.

TABLE B

Time	Room Temp.	Thermometer Numbers 1	2	3	4	5	6	7	8	9	Mean
0	33.5	30.9	31.1	31.3	37.3	37.2	36.6	37.7	31.7	34.4	34.2
15 Min.	33.2	30.2	30.6	31.1	36.9	36.9	36.6	36.8	31.4	34.4	33.9
30 Min.	33.0	30.0	30.3	30.8	36.9	36.9	36.5	36.7	30.8	34.2	33.6
45 Min.	33.2	30.3	31.1	31.2	36.8	36.9	36.6	36.7	31.7	33.9	34.0
Mean	33.2	30.4	30.8	31.1	37.0	37.0	36.6	37.0	31.4	34.2	34.0

Mean Ambient − Mean Room = 34 − 33.2 = 0.8 deg. cent.

three thermometers placed around, and about 20 ft. from the set.

Oil cups, although desirable in testing large machines of continually increasing temperature, were omitted because the unit was of small size, and had been al-

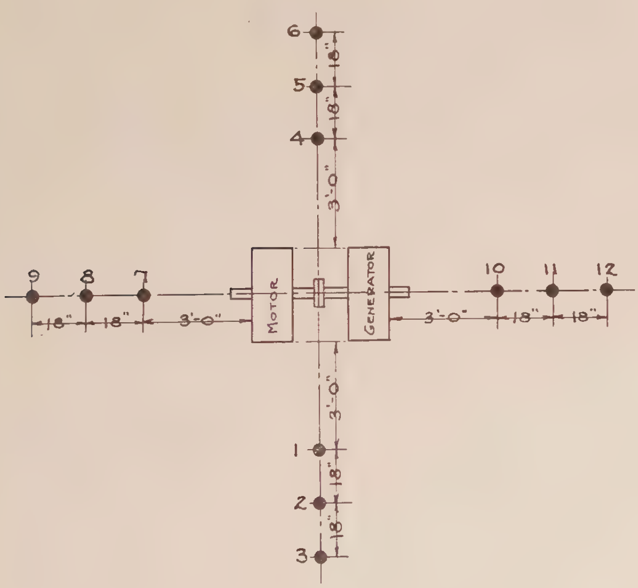

Fig. 1

lowed to run long enough to attain a sensibly constant temperature before readings were taken. Four sets of simultaneous observations, shown in Table A, were recorded at 15 minute intervals.

The data show an average room temperature of 27.5 deg. cent., and an ambient temperature of 28.0 deg. cent., obtained by averaging all the readings of the 12 thermometers. The difference between the two temperatures is 0.5 deg. cent.

A closer analysis brings out several interesting points, which have a bearing not only upon the actual temperature difference, but also upon the conciseness of the ambient temperature rule itself.

The relatively small difference of 0.5 deg. cent. shows that, for small machines, actual machine temperature has little effect on ambient temperature. Had the unit been running at only 100 per cent load, and consequently, normal temperature, the difference of the temperatures would have been still smaller. It is to be expected that a small unit, generating only a comparatively small amount of heat, has a correspondingly small heating effect on its surrounding air. However, the heating effect of a large unit, emphasized by a strong fanning action, no doubt will have considerable effect on ambient temperature, and will depend principally upon the actual machine temperature, its size, and the size of the room containing it.

Due to the presence of a slight draft, or to the fanning effect of the armatures, the mean temperatures on the four sides of the machine differ. For instance, the average of readings No. 1, 2 and 3 is 27.5 deg. cent., of 4, 5 and 6 is 28.3 deg. cent.; of 7, 8 and 9, 28.6 deg. cent; and of 10, 11 and 12, 27.7 deg. cent. A considerable fanning action would increase this temperature difference to some extent. Moreover, the mean value of T_7 is 1.7 deg. cent. greater than that of T_1 although both are equidistant from the machine. If, for instance, as a result of carelessness, a majority, or all of the thermometers are placed on the hot side of the machine, an ambient temperature would be obtained which would differ by several degrees from the correct value, and still conform to rule 2300. The ambient temperature obtained by averaging the readings on the two hot sides is 0.85 deg. cent. above that of the two cool sides.

These inaccuracies are, of course, small in so small a unit, but in a larger machine they may be greater and thus the number and location of thermometers can be of considerable importance.

Test on Steam-Driven Unit

The machine tested is one of three 90-kv-a., direct-connected (reciprocating engine) alternators at the Washington University power plant. All three units are located in the same room and the test was made under actual working conditions. The load on the generator had been constant at 50 per cent of rating for several hours previous to the test, and remained practically unchanged while the observations were being made.

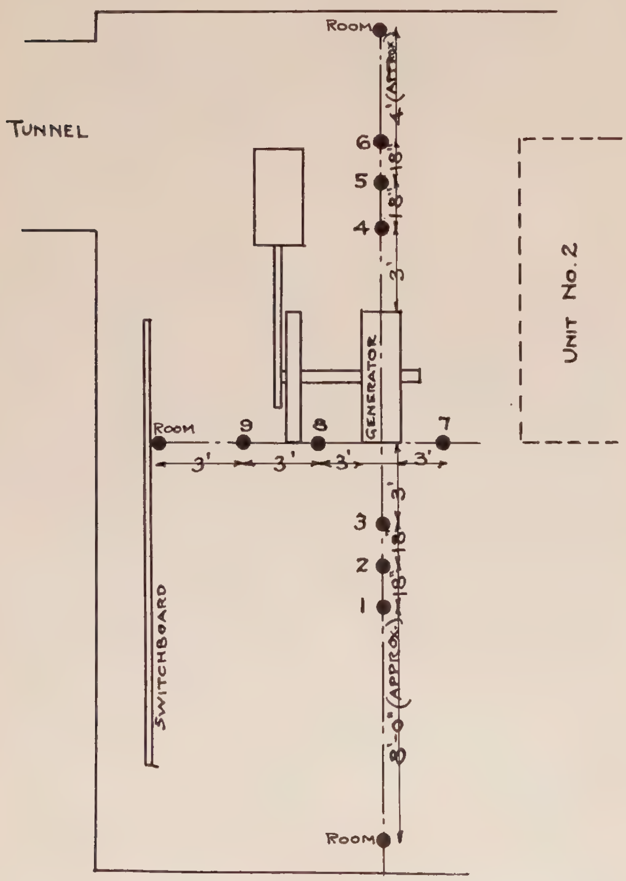

Fig. 2

It was impossible, because of nearby apparatus, to place thermometers in four radial lines as in the previous case. Instead, 9 thermometers were placed at convenient points within the 3 to 6 ft. zone as shown in Fig. 2 and three thermometers were placed near the engine room walls to measure room temperature. All were hung in a horizontal plane level with the shaft.

As before, four observations were taken over a period of one hour (Table B). A mean of all ambient readings over this length of time gives a result of 34.0 deg. cent., with an average room temperature of 33.2 deg. cent. The difference is 0.8 deg. cent., as compared with a maximum value of 1.05 deg. cent. obtained on a similar size turbine driven unit by W. B. Kouwenhoven[2] of Johns Hopkins University. However, no particular significance should be attached thereto for the reason that, in the test described, room temperature varied from 29.1 deg. cent., at one point, to 33 deg. cent. near the switchboard, and jumped to 37.5 deg. cent. at the steam side of the room. Therefore, room temperature, in this test and in similar ones on direct-connected, steam-driven units, is an unknown quantity and can be varied several degrees by changing the number or location of the room temperature thermometers.

The results obtained, because of their very uncertainty, show that in the case of direct-connected, steam-driven units, however small, it is impractical and inaccurate to approximate ambient temperature by adding a fixed increment to room temperature.

Summary

1. The actual temperature of a small machine is of slight importance in its effect on ambient temperature. The size of the unit is the more important factor.

2. If ambient temperature measurements are to be uniform, it is necessary to read temperature, not merely at different points around the machine within the 1-2 meter zone, but at points *symmetrically* around, and at *definite distances* from the machine. Fig. 1 suggests one arrangement. If, due to nearby apparatus, a symmetrical arrangement is not possible, slight modifications should be made to fit particular conditions.

3. The difference between ambient and room temperatures as obtained in the test on the 6-kw. motor generator set is 0.5 deg. cent. The combined capacity of motor and generator at 150 per cent load amounted to 18 kw. On a larger unit the above difference would increase perhaps to 1 or 1.5 deg. cent. at 100 kw. It seems desirable, therefore, in testing small machines located in rooms of fairly uniform temperature, to omit ambient temperature measurements entirely and add, instead, a fixed increment to room temperature.

4. The method outlined in the preceding paragraph is not applicable to direct-connected, steam-driven generators or to machines located in rooms of uneven or variable temperature. Under such conditions a symmetrical or nearly symmetrical arrangement of thermometers around the machine is the logical method of determining ambient temperature.

2. Jour. A. I. E. E., Sept. 1922.

A Method of Calculating the Ampere-Turns for Driving a Magnetic Flux Through Wedged-Shaped Teeth

BY BORIS WOROHOFF

Technological Institute, Petrograd

THERE are several methods of calculating the ampere-turns necessary to drive a certain magnetic flux through wedge-shaped teeth. Some of these methods give a very incorrect result, as, for instance, the method by the mean value of the sectional area of the tooth. A few other methods give a perfectly correct result, but require much time or special curves for every fixed form of tooth and a definite kind of material.

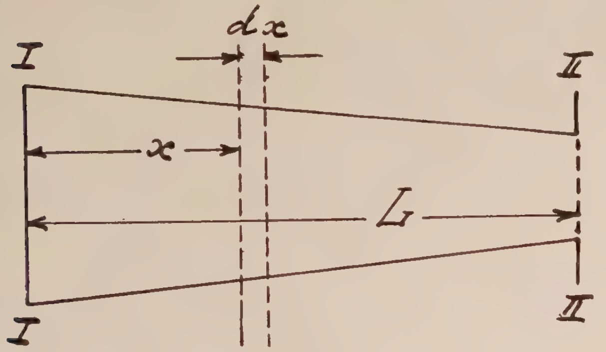

Fig. 1

In Vol. 57 of *Electrical World* (1911 p. 111) Mr. A. Miller Cray gives some very interesting results by comparing different methods of calculating the ampere-turns in the case of wedge-shaped teeth.

I propose the following method giving perfectly correct results, provided we neglect the flux passing through the slot by the tooth.

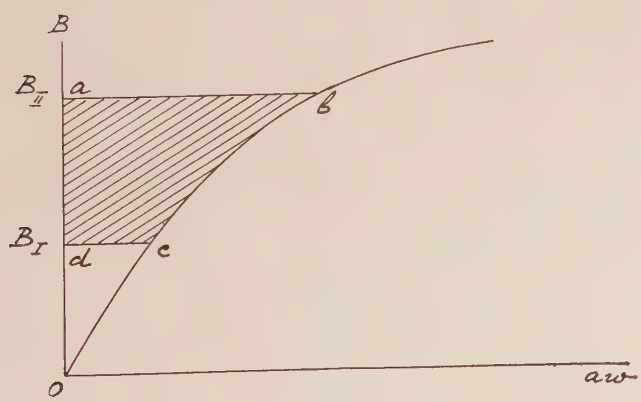

Fig. 2

Let B_{I} be the magnetic induction at the widest part $(I - I)$ of the tooth and let B_{II} be the magnetic induction at the narrowest part $(II - II)$.

Let B_x be the induction at the cross section being at a certain distance x from the top. Then we have

$$B_x = B_{I} + (B_{II} - B_{I})\, x/L$$

By differentiating we have

$$d\,B_x = (B_{II} - B_{I}) \frac{d\,x}{L}$$

thus

$$d\,x = \frac{L}{B_{II} - B_{I}}\, d\,B_x$$

For driving a certain magnetic flux through an element of the length $d\,x$ is necessary $a\,w_x \,.\, d\,x$ ampere-turns. For the whole length of the tooth L will be necessary

$$A\,W = \int_0^L a\,w_x\,d\,x = \frac{L}{B_{II} - B_{I}} \int_{B_{I}}^{B_{II}} a\,w_x\,d\,B$$

If in the case of a certain kind of iron we have a curve expressing the dependence of B (magnetic induction) from $a\,w$ (ampere-turns for 1 cm. of length), then

$$\int_{B_{I}}^{B_{II}} a\,w_x \,.\, d\,B_x = (\text{area } a\,b\,c\,d) \,.\, a\,w_0 \,.\, B_0$$

In a diagram the horizontal distance represents the magnetizing forces (1 cm. = $a\,w_0$ ampere-turns) and the vertical distance represents the magnetic induction (1 cm. = B_0 hauss). It will be found, that

$$B_{II} - B_{I} = \overline{a\,d} \,.\, B_0$$

and we have

$$A\,W = \frac{L}{\overline{a\,d} \,.\, B_0} (\text{area } a\,b\,c\,d) \,.\, a\,w_0 \,.\, B_0$$

$$A\,W = \frac{L}{\overline{a\,d}} (\text{area } a\,b\,c\,d) \,.\, a\,w_0$$

Hence the solution of this problem reduces itself to the measuring of the shaded area $a\,b\,c\,d$ which can be easily and quickly done with the planimeter.

WATER POWER PROJECT IN EASTERN ALGERIA

According to the Semaphore of July 13, 1923, Constantine, the capital of Eastern Algeria, is to have installed, for the benefit also of its neighboring towns, two dams, for developing power and light. One dam at Kreneg is to be about 115 feet high, which will provide a storage reservoir of 41,000,000 cubic feet capacity. The cost of this plant is estimated at 13,200,000 francs. About 5,790 horse power will be available. The lower dam, called the Beni-Haroun, will be 130 feet in height, with a canal 650 feet long. The power available will be about 2,175 horse power and the cost of construction 7,000,000 francs.

The Starting of Polyphase Squirrel-Cage Motors

BY BENJAMIN F. BAILEY

Fellow, A. I. E. E.

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Review of the Subject.—*In view of the large size of modern power houses we should change our views regarding the need of starters. The different methods of starting polyphase induction motors are briefly reviewed and the speed torque curves obtained with various types are considered. The effect of starting current upon line voltages, upon the motor and upon connected apparatus is taken up. It is shown that the performance of the compensator is poorer than ordinarily assumed and that the effect upon the line voltage is less with a resistance starter than with a compensator. It is also shown that the heating of the motor is least when thrown directly on the line. The energy required with the various methods is also considered. In large installations it is shown that the considerations involved are radically different.*

In Appendix A, proof is given that the effect upon the line voltage, is less with a resistance starter than with a compensator. In Appendix B the detailed computations involved in deriving some of the curves are given in full.

CONTENTS

When polyphase squirrel-cage motors of considerable size were first used, it was found necessary to provide means to apply a lower voltage to the motor terminals while the motor was being started, in order to reduce as much as possible the current and power taken from the line. If this was not done the excessive current resulted in a great reduction of the voltage of the generator which sometimes made it impossible to start the motor at all and caused a great reduction of the candle power of any lamps connected to the circuits.

With the large capacity power stations which we now have, the load due to starting any induction motor of moderate size is inappreciable so far as the generating station is concerned. The reduction in voltage in lamps connected to the same transformers as the motor may still be a serious matter, although with the larger transformers now in use this is less serious than it formerly was. It seems that this is an appropriate time to examine carefully into the necessity for starters in view of the changed conditions in central station distribution.

Many central stations have a rule to the effect that no polyphase squirrel-cage motor of more than 5 h.p. may be connected to their lines unless it is provided with a starter. Many users of such motors seem to be under the impression that something dreadful will happen in case an attempt is made to start a good-sized induction motor by connecting it directly to the line. It is the purpose of this paper to try to dispell this illusion and to examine carefully into the conditions under which a starter may or may not be necessary. It will be shown that the supposed bad effects of throwing a motor directly on the line do not, in a majority of cases, materialize and that in many cases, it is better for everyone concerned to connect motors directly to the line instead of through starters.

An examination of any price list of polyphase induction motors will disclose that this is a question of decided economic importance. A comparison of the price of motors and starters will show that the price of a compensator varies from approximately 20 per cent to 70 per cent of the cost of the bare motor, an average figure would perhaps be 40 per cent. If it can be shown that a starter is not only unnecessary but is actually detrimental to the best interests of the installation as a whole it will be obvious that we can effect a large saving. It is to the interest of every one concerned to reduce the price of a motor to the lowest possible figure. The manufacturers of motors will benefit through the increased demand for their product. If the cost of installation of a motor can be reduced, say 25 per cent, the number of motors used will unquestionably be greatly increased. The central station will obviously benefit through the increased use of its product and it requires no argument to show that the purchaser of the motor receives a direct benefit.

Method of Starting

In the following diagrams and descriptions the three-phase motor only will be considered. The remarks, however, will apply equally well to the two-phase motor with the obvious necessary changes in connection. The single-phase motor is in a class by itself and no attempt will be made to treat it here.

There are in use at the present time three distinct methods of starting polyphase squirrel-cage induction motors; first, by throwing them directly on the line, second, by the use of the resistance starter and third, by means of the auto-starter or compensator. The star-delta method of starting may be regarded as a special case of the latter. Most small motors are started by connecting them directly to the line. Large motors are almost invariably started by means of compensators. The use of the resistance starter is generally confined to motors between 5 and 25 h. p.

The first method is not shown, but the connections are identical with those of Fig. 1, if we imagine that the starting resistors are omitted. The switch is first thrown to the left and the motor takes current directly from the line through the starting fuses. As soon as full speed has been obtained the switch is thrown to the right and the motor is then connected to the line through smaller fuses. The heavy starting fuses are necessary since the motor takes a momentary current equal to about five times the full-load running current. The starting fuses may be omitted in case the line is properly fused elsewhere to take care of the starting current. It is highly desirable that the switch be so constructed that it cannot be left on the starting position. It is also better if the construction is such that contact is made with the terminals of the running fuses before contact is broken with the starting fuses and the further movement of the operating handle entirely disconnects the starting fuses. This avoids a bad rush of current when the switch is momentarily opened and will be referred to later.

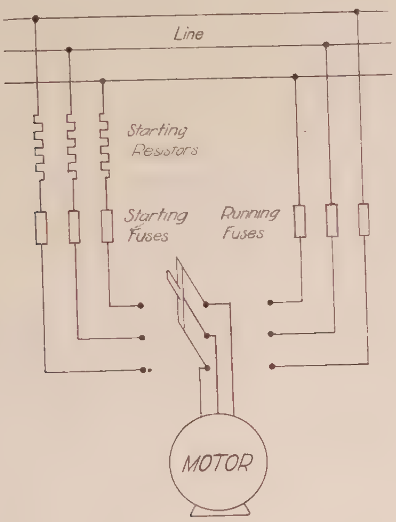

Fig. 1

Resistance Type Starters

The connections for this method are shown in Fig. 1. The same remarks as regards the proper arrangement of the switch apply here. There should be a position of the switch in which the motor is completely disconnected, another in which the connection is made through the resistors and starting fuses. A further movement of the starting handle should connect the starting resistors and starting fuses in parallel with the running fuses and the final position should leave the motor connected to the line through the running fuses. The switch should be so constructed that it cannot be left permanently in the second or third positions mentioned.

Starting by Means of a Compensator

This method is illustrated in Fig. 2. A three-phase auto-transformer is employed and is connected to the line through heavy starting fuses as shown in Fig. 2A. Three taps are led from the windings of the auto-transformer to the three terminals of the motor. Usually provision is made so that the voltage applied to the motor may be approximately 50 per cent, 65 per cent or 80 per cent of the line voltage. After the motor has come up to speed the connections are changed to those shown in Fig. 2B. The auto-transformer is entirely disconnected from the line and the motor is connected to the line through running fuses.

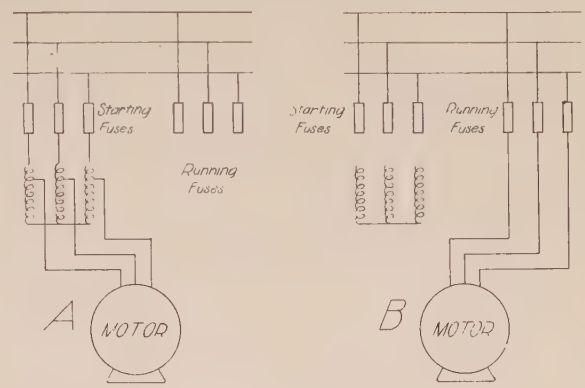

Fig. 2

A modification of this method is shown in Fig. 3. In this two transformers connected in open delta are used instead of one three-phase transformer. Another method for obtaining the equivalent of reduced voltage when starting is to provide the motor with six leads and connect it in star for starting and in delta for running. By this method 58 per cent of normal voltage is applied to each winding of the motor during the starting period.

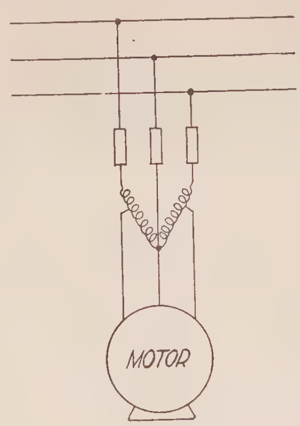

Fig. 3

The speed-torque curve of a motor connected directly to the line is shown in Curve 1 of Fig. 4. At standstill the motor develops a torque proportional to the length OA. As it accelerates the torque increases, reaching a

maximum proportional to $B\,C$ at about two-thirds of full speed. If the torque of the load to be driven is represented by the line $D\,E$ it finally reaches a speed represented by $E\,H$. It is well known that the shape of the speed-torque curve can be varied through wide limits by changing the rotor resistance. The curve shown is an average one for the usual squirrel-cage motor.

Curve 3 of Fig. 4 represents the speed-torque curve of the same motor when started at reduced voltage by

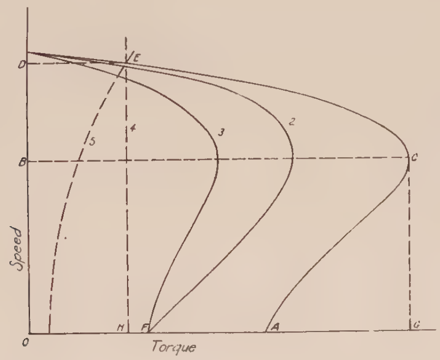

Fig. 4

means of a compensator. The torque developed in the rotor for a given speed is approximately proportional to the square of the applied voltage. The actual torque delivered to the shaft is reduced in a somewhat greater proportion since friction of the bearings is a constant quantity. It will be obvious that the applied voltage cannot be very greatly reduced or the torque developed will be insufficient to start the load. Usually the voltage of the lowest taps on a compensator is 50 per cent of line voltage giving a torque at the shaft (taking account of the bearing friction) of about 20 per cent of that developed at full voltage. Since the torque developed at full voltage varies from 200 per cent of full-load torque to as low as 120 per cent, the delivered torque at 50 per cent of line voltage will be from approximately 40 per cent to 24 per cent of the full-load torque. The 65 per cent and 80 per cent taps give of course correspondingly greater torques.

Curve 2 of Fig. 4 represents the speed-torque curve of a motor starting through a resistance starter. In drawing this curve it has been assumed that the resistance is such that the motor receives exactly the same current at standstill as it received when started through the compensator; in other words the resistance is such that the voltage applied to the motor at standstill is exactly the same as in curve 3. The standstill torque is therefore exactly the same. As the motor speeds up however, the current taken from the line becomes very much less and the drop over the starting resistance therefore becomes less. The voltage applied to the motor terminals increases and the torque developed at any speed, except standstill, is greater than with the compensator method of starting. The exact shape of the curve is dependent upon the resistance and reactance of the motor and the one drawn can be regarded only as a typical curve for this type of motor.

The speed-torque curve of the load to be started is also of great importance. Curve 4 of Fig. 4 shows the curve of a load demanding constant torque at all speeds. This would be approximately correct for a load having considerable friction, for example, a line shaft driving a number of belts. Curve 5 of Fig. 4 shows the speed torque curve of a fan. The torque required should theoretically vary in proportion to the square of the speed. In practise there is added to this an approximately constant torque necessary to overcome the friction of the bearings. A third type of load is one having no friction whatever, but only inertia. A heavy flywheel mounted on ball bearings approximates this condition. If all friction could be eliminated the torque required would be zero and the line $O\,D$ would correctly represent the speed torque curve.

The horizontal distance between any one of these load speed-torque curves and any one of the curves 1, 2, or 3, represents the torque available for acceleration. The load of course develops a back torque due to its inertia, exactly equal to the horizontal difference between the two curves considered. The time required to bring the load up to full speed is a function of this difference and the inertia of the load.

Effect of Starting Current Upon Line Voltages

The current taken in starting an induction motor causes a reduction in the line voltage. If the constants of the line and of the transformer, if one is used, are known, this reduction can be computed by the method shown in Fig. 5. In making this diagram the effect of resistance has been ignored since this is usually a minor factor compared with the reactance.

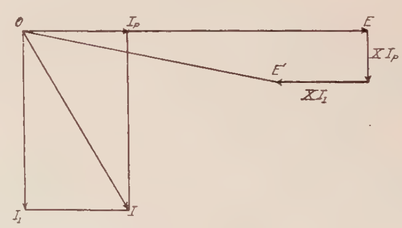

Fig. 5

In Fig. 5 the line voltage before the motor is connected to the line is represented by the vector $O\,E$. The vector $O\,I$ represents the starting current lagging by a large angle behind $O\,E$. For the purpose of analysis this current may be regarded as divided into two components; the component $O\,I_p$ in phase with the line voltage and the current $O\,I_1$ lagging 90 deg. behind the voltage. Each of these components generates a voltage at right angles to itself and proportional to the reactance of the line and transformers. These voltages are

represented by $X I_p$ and $X I_1$. The terminal voltage applied to the motor then becomes $O E'$. The effect of connecting the motor to the line has then been to reduce the voltage from the value $O E$ to $O E'$. It will be noted that the component $X I_p$ has but small effect upon the absolute value of the line voltage since it is at right angles to it, but the component $X I_1$ is directly subtracted from the line voltage. It is therefore apparent that the lagging or wattless component of the starting current is the one that is mainly instrumental in influencing the line voltage.

In case the resistance of the line is high we can readily take account of its effect by adding another vector, equal to the resistance of the line multiplied by the total current and in phase opposition to the total current $O I$. The fact that the bad effect of the starting current is due primarily to the lagging component of the line current is of importance and will be referred to later.

Effect Upon Connected Apparatus

It now becomes necessary to consider in some detail the various effects of starting by the three different methods indicated. In some cases it is impracticable to connect the motor directly to the line on account of possible injury to the connected machine. For example, some motors give as high as 200 per cent or even more starting torque and a maximum torque of perhaps 300 per cent. If such a motor is connected to its load by means of a belt, the belt may slip excessively during the starting period. This will be particularly true if the belt and pulley are of insufficient size or if proper provision is not made for tightening the belt. The bad effects will be particularly noticeable if the connected load has large inertia. A typical example of this would be a motor belted to a punch press by means of a vertical belt, the punch press being equipped with a heavy flywheel. Such cases should in general be taken care of by the provision of ample belt and pulley capacity.

Usually the torque developed by a squirrel-cage induction motor is low enough so that no fear need be entertained that the connected machine will be injured by the rapid starting. So far as the motor is concerned any polyphase induction motor built by a reputable manufacturer will readily stand the strains imposed by starting at full voltage.

Heating

The first thought of nearly anyone who has not given the subject detailed consideration is that a motor will heat excessively if started by throwing it directly on the line. The exact reverse of this is true. The heating will be far less if the motor is thrown directly on the line than when started by any other method. The starting period is so short that practically no heat is carried away from the motor by radiation. The rise in temperature of the motor during starting is proportional to the average loss multiplied by the time, and since the losses are mostly copper loss the heating is proportional to $I^2R\,T$. If the starting current is reduced to say one half its locked value by means of a compensator the rate of heating will be reduced to one quarter. The starting torque, however, is also reduced to one quarter and if the load consisted of inertia only, that is, if all friction could be eliminated both from the load and from the motor the time required to start would be four times as great. The rise in temperature of the motor would then be exactly the same whether started at full voltage or at reduced voltage. Practically, it is of course impossible to eliminate friction and it will be readily seen from Fig. 4 that under the assumed conditions the time required to start will be more than four times as great, since only the excess of the starting torque over the frictional torque is available to produce acceleration and therefore the heating will be greater when the motor is started at reduced voltage.

As an extreme case, if the starting torque were so greatly reduced that it became less than the static torque of the connected load the motor would refuse to start at all and the rise in temperature would in time become excessive. So far as heating of the motor is concerned, there is therefore nothing to be gained by using a starter. In fact, if it were necessary to reduce the heating of the motor during starting it could be done by using an inverted auto-starter which would apply more than line voltage to the motor during the starting period.

Starting Currents

The Compensator. If we start a motor by connecting it to the line through auto-transformers the current taken by the motor is reduced nearly in proportion to the applied voltage. The torque of the motor is reduced approximately in proportion to the square of the applied voltage. The current taken from the line is less than the current in the motor in the ratio of the reduction of the voltage and therefore both the line current and starting torque are reduced in the same proportion, namely in proportion to the square of the applied voltage divided by the line voltage. This, however, neglects the losses in the auto-transformer and the static torque of the bearings of the motor. We thus arrive at the conclusion that neglecting the losses in the compensator and the bearing friction of the motor, the torque delivered is proportional to the line current, or the amperes per foot pound torque is constant. Similarly, it will be apparent that the watts per foot pound torque is constant. Actually, the line current and watts will be greater than indicated by the above ratio and the effective torque of the motor will be less.

To show these facts in an actual case a 10-h.p., 1800-rev. per min., 3-phase, 60-cycle, 220-volt squirrel-cage induction motor was tested in connection with a

10-h. p. compensator. When the motor was connected directly to the line the results were as follows:

Volts	Amperes	Kilowatts	Torque
220	189.5	40.0	98.5

The motor was then connected to the 65 per cent taps of the compensator and the corresponding readings taken on both the line and the motor sides of the compensator. The results were as follows:

Volts Line	Volts Motor	Amperes Line	Amperes Motor	Kilowatts Line	Kilowatts Motor	Torque
220	134.7	75	110	15.7	13.9	25

It will be seen that the current taken from the line was reduced from 189.5 amperes to 75 amperes. In accordance with the above analysis the torque should be reduced in the same proportion or to 39 lb. ft. The actual torque developed was 25 lb. ft. or 64 per cent of the theoretical value. A similar computation can be based upon the fact that the kilowatts from the line were reduced from 40 to 15.7 giving an almost identical value for the torque. It will thus be apparent that the introduction of a compensator increased the amperes and the kilowatts per lb. ft. of torque about 56 per cent.

The results of the computation can also be expressed as follows:

Theoretical current to give 25 lb. ft., 47.8 amperes.
Actual current to give 25 lb. ft., 75 amperes.
Excess of actual over theoretical, 56.8 per cent.
Theoretical kilowatts to give 25 lb. ft. torque, 10.15.
Actual kilowatts to give 25 lb. ft. 15.7.
Excess of actual over theoretical, 54.8 per cent.

It may be of interest to note that the above figures show that the efficiency of the compensator is 88.5 per cent. An independent test made by a somewhat different method showed an efficiency of 87.3 per cent.

As these results were surprisingly unfavorable to the compensator it was thought well to supplement them by other tests. A test was made upon a 7½-h. p., 1200-rev. per min., 3-phase, 60-cycle, 220-volt squirrel-cage induction motor with its starter of corresponding rating. Both motor and starter were built about 15 years ago and are of much more liberal design than modern machines. The results are shown in Fig. 6. Tests were made on all three taps with which the motor was equipped and also with the motor directly on the line.

The straight line running from the origin gives the value of the line current that would be required if the losses and leakage of the transformer and the bearing friction of the motor could be ignored. This is the current that is ordinarily assumed in discussions of the use of compensators. The actual line current is shown by the curved line marked line current. The third is the motor current or the current that would be taken from the line if a resistance starter were used. The fourth curve is the ratio of the "theoretical" current and the actual line current, and for lack of a better name has been called the "current efficiency" of the compensator. It will be seen that even with a very liberally designed compensator the results fall decidedly below 100 per cent, although they are much better than in the case of the other compensator tested.

It is of course obvious that the above two tests by no means exhaust the subject of compensator efficiency. They serve however to give an indication of the results to be expected in practise.

The arrangement shown in Fig. 3 in which two single-phase auto-transformers are used instead of one polyphase transformer is in common use. With this arrangement there is a further reduction in torque due to unbalanced voltages. The currents in the line

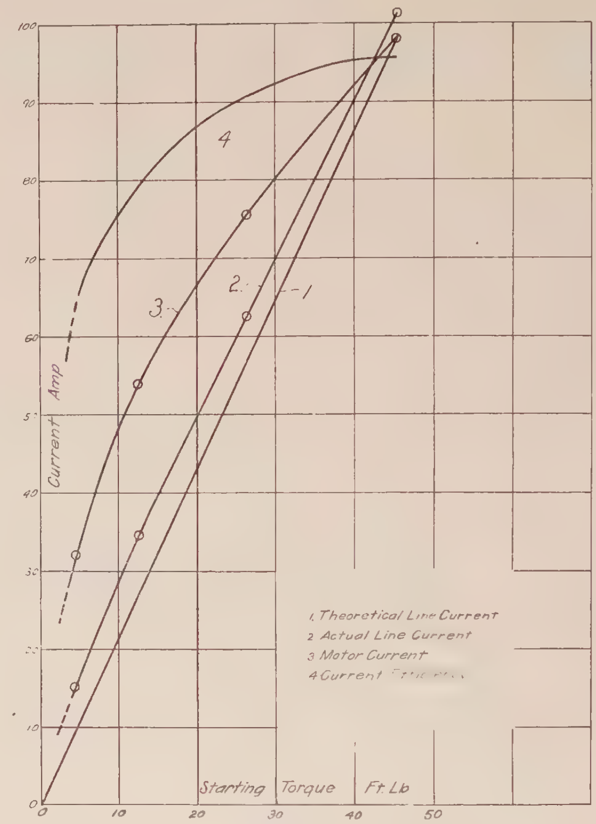

Fig. 6

also become somewhat unbalanced. This effect is not very serious but is nevertheless decidedly appreciable.

If the connected load has a small starting torque (for example a fan load) the initial current taken from the line can be quite materially reduced by using a compensator for starting. If the load, however, has a high static torque it is frequently necessary to impress 85 per cent of the line voltage upon the motor terminals. If the impressed voltage is 85 per cent of the line voltage the starting current taken from the supply mains with a perfect transformer would be 72 per cent of the current which the motor would take without a starter. Allowing for the losses in the starter and the possible unbalancing of the voltages the actual current will be from 80 to 90 per cent of the locked current and the

torque developed allowing for the friction of the motor about 70 per cent of the locked torque. In the case of a motor starting a heavy load, it will be well worth while to consider whether a possible saving of 10 to 20 per cent of the momentary starting current is worth while in view of the expense and complication of a starter.

As the motor speeds up the difference between what the motor would take if thrown directly on the line and what is taken from the line through the compensator rapidly becomes less and in fact if a motor carrying full load is allowed to accelerate to its highest speed the current taken with the starter will become greater than that which would be taken without it.

There is another point in this connection however which is not generally known. The greatest current taken from the line in starting a motor by means of the usual compensator occurs not when the switch is first closed with the motor at rest, but at the moment when the motor is disconnected from the starter and thrown directly on the line. The magnitude of this latter current depends upon the exact instant when the transfer is made and the length of time required in changing the connection. The momentary rush of current when the motor is finally connected to the line may be as much as four times the locked current which the motor takes when connected with the line at standstill. Thus, if a motor took a maximum of 100 amperes at standstill when connected directly to the line it might take an initial current of say 50 amperes when connected through an auto-starter. The momentary current when the starter is thrown from the starting to the running position might be as high as 400 amperes or more. With large motors, instances have been known of the starter and motor being injured due to this momentary enormous current.

The explanation is simple. When the motor has been running at reduced voltage and is disconnected from the line the stator current of course drops to zero, but the rotor current continues to flow for some time. As soon as the motor is disconnected, the flux of the motor begins to decrease and this decrease induces a voltage which tends to keep the rotor current flowing. The rotor therefore continues to revolve and the rotating field revolves with it, but at a speed less than synchronous speed. The rotating flux generates a voltage in the stator, the frequency of this voltage being of course somewhat less than the line frequency. The phase relation of the line voltage to the induced motor voltage is therefore constantly changing and the two voltages will not in general be in phase opposition when the motor is finally thrown on the line. The result is therefore similar to that which would follow if an attempt were made to connect a synchronous machine to a supply circuit without attempting to synchronize it. If the two voltages happen to be in phase coincidence the condition will be the worst and there will be a very large momentary rush of current. If they are in phase opposition the condition will be the best possible and the rush of current will be comparatively small. It is probable that the period during which this excessive current flows is so short that the effect upon electric lamps connected to the same circuit is more or less negligible, but it is obvious that the sudden reduction in voltage due to this large current may have a serious effect upon connected synchronous machinery and may set up a surging in such machinery which will have a considerable disturbing influence.

This phenomenon is fully treated in an article by R. E. Hellmund, TRANSACTIONS of the A. I. E. E., February 16, 1917.

The Resistance Starter. Turning to the resistance-type starter it will be seen that the initial starting current in the motor for the same torque developed will be the same as with the compensator, but the line current will of course be greater, being the same as the motor current. With the same assumption as previously made, namely, that the terminal voltage on the motor is 85 per cent of the line voltage, the resistance type starter would take 85 per cent as much current as would be taken by the locked motor. As was previously shown the current taken by the compensator would be from 80 to 90 per cent of the locked current. Starting on the high-voltage taps of the compensator the line current taken is not much less with the compensator than with the resistance-type starter. If the iron of the compensator is worked at a high density, so that the magnetizing current of the compensator is large, the current may be less with the resistance starter. The relation between the two is shown in Fig. 6.

As was shown previously however, it is not the current alone which is of importance in determining the degree to which the line voltage will be disturbed but the wattless component of the starting current. It can be readily shown (see appendix A) that the wattless current at start in the two cases is exactly the same provided we neglect the losses and the leakage reactance of the auto-starter. Actually the wattless component of the starting current is decidedly greater with the auto-starter than with the resistance type starter.

Thus in the case of the motor first considered, the line current was 75 amperes. It can be readily shown that the power factor or cosine of the angle of lag was 0.55. The sine of the angle of lag was 0.836 and the lagging component of current $0.836 \times 75 = 62.7$ amperes.

The same motor with a resistance starter takes 110 amperes at 220 volts to develop the same torque. The power factor however rises to 0.86 and the sine of the angle of lag is 0.513. The lagging component of current is therefore $0.513 \times 110 = 56.5$ amperes. The wattless component of the line current is therefore in this case only 90.2 per cent as much with the resistance starter as with the compensator.

Fig. 7 shows the relative value of the wattless

components of current for the compensator and the resistance-type starter in the case of the second motor tested. From Fig. 6, the wattless components of line currents were computed in the case of both the resistance-type starter and the compensator. It will be seen that the wattless component, which is mainly responsible for the drop in line voltage when a motor is started, is materially larger with the compensator. The method of computing the points for the curves of Fig. 7 is explained in detail in appendix B.

To confirm the above conclusions, tests were made of the drop in voltage when the same motor was started first with a compensator and then with a resistance starter. The motor current and the torque developed

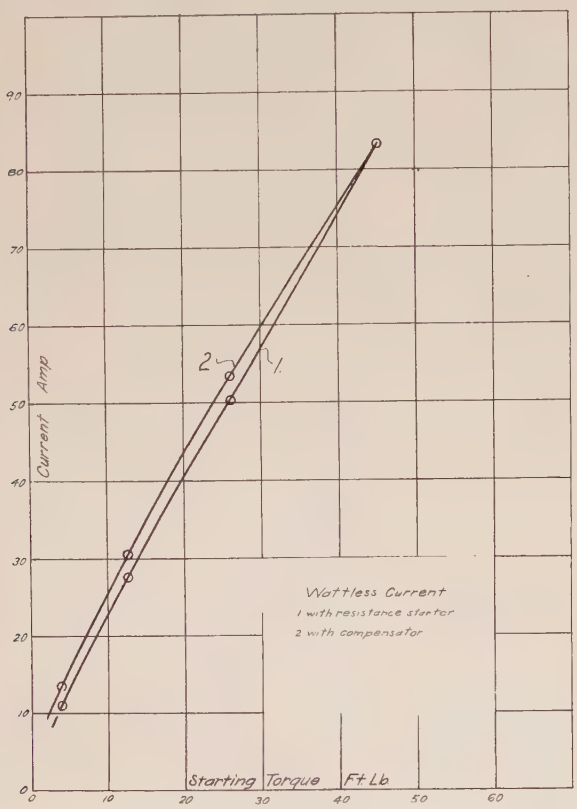

Fig. 7

were the same. No difference could be detected in the momentary drop in the two cases but the disturbance was of shorter duration with the resistance starter.

We may conclude that the drop in voltage when a motor is started is very nearly the same whether a compensator or a resistance starter is used.

Frequently the case is even more favorable for the resistance-type starter since these are usually so constructed that a relatively high resistance is inserted at the start and this is gradually cut out until the motor starts. The motor is therefore started with the minimum possible disturbance to the line. Moreover, even though no provision is made for cutting out the resistance gradually, the motor need never be entirely disconnected from the line. There is, therefore, no reason for a large momentary rush of current as described in connection with the compensator method of starting.

It should be mentioned, in justice to the compensator, that in the case of compensators for large motors, provision is sometimes made so that the motor is never entirely disconnected from the line and this large momentary rush of current is therefore avoided. This is done, however, only with a considerably increased expense and complication.

In this connection it may be of interest to note that the Carnegie Steel Company of Duquesne, Pennsylvania is now attempting to do away with all auto-transformers in motors up to 100 h.p. Resistance-type starters are being used instead. It is stated that in one instance a 200 h.p. motor is being operated with a one step resistance starter without any difficulty (see *Proceedings* of the Association of Iron & Steel Electrical Engineers for 1921. Page 291.)

Star Delta Starting. The star-delta method of starting has several points of advantage when it can be used. The voltage across a winding at start is 58 per cent of the line voltage. The torque is, however, reduced in proportion to the square of the applied voltage or to one third of the locked torque. A simple calculation will show that the current is reduced in the same proportion. By using this method the expense of transformers and the loss incident to their use is avoided. The method however is inflexible in that only one value of starting torque can be obtained and that only one third of the locked torque. Unless the starting load is light it is therefore usually impossible to make use of this method. The cost of bringing out the leads and providing a delta winding for the motor is also considerable.

It may be worth while noting that in the case of two-phase motors, by providing two separate circuits in each phase it is possible to obtain a starting torque of one quarter of the locked torque with one quarter of the locked current or one half of locked torque with one half of locked current depending upon the connection used. To obtain one half the torque at starting requires a change from the series connection to a so-called box connection.

Energy Required

The power taken from the line will be greatest when the first method is used, namely, connecting the motor directly to the line. The time required to start is however so much reduced that the energy required will be less with this method than with either of the others.

Comparing resistance type starting with that by means of a compensator it will be obvious that the resistance method requires a greater amount, both of power and of energy. This is of course due to the loss in the resistors employed. Unless a motor is being continually started and stopped the actual

difference in the power bill will be inappreciable. This will be particularly the case when the starting conditions are severe.

In considering the bad effect upon voltage regulation the lagging component of the current is not the only element that should be taken into account. If the current alone were considered the compensator would be hopelessly outclassed, since, as previously shown, momentary current may reach a very high value. The time during which the current lasts should also be considered. It is difficult to say what the exact criterion should be. If we assume however that the bad effect of the voltage disturbance is proportional to the product of the wattless current and the time during which it flows, it will be apparent in view of what has been said that the disturbance will be least when the motor is thrown directly on the line, somewhat greater with the resistance-type starter and greatest of all with the compensator method of starting. The author would not care to maintain that the product of the wattless current and the time is necessarily the best criterion, but it is perhaps as good as any that we know of at the present time. The question is a very involved one so far as the effect of poor regulation upon lighting is concerned on account of the psychological effects involved.

Effect in Large Installations

So far, we have considered starting as applied to a single motor only. When a large number of motors are supplied from the same transformer or other source the conditions become radically different. Suppose, for example, that a single transformer feeds three motors of respectively 7½, 50 and 100 h.p. The installation rules of most central stations require that all these motors be provided with starters. Perhaps some companies would even insist that these starters be of the compensator type to avoid the supposed bad effect of the larger starting current taken by the resistance-type starter. The fallacy of this supposition has been previously shown. It is difficult to understand why the 50-h. p. and the 7½-h. p. motors must be equipped with starters when the maximum current which the 50-h. p. motor can take when thrown directly on the line is less than that taken by the 100-h. p. motor starting through a compensator and that of the 7½-h. p. motor is far less. Some companies, notably the Philadelphia Electric Company have been far-sighted enough to recognize this fact. The rules of the above mentioned company state "Where an installation consists of a number of motors, the starting device may be omitted from any motor which, with the starting device omitted, would have a starting current less than the permissible maximum for the largest motor (other than a fire pump motor) in the installation."

It is possible to go still further and show that when a large number of motors are installed in a factory the maximum current and the maximum kilowatts taken from the supply lines will be *less* if the motors are thrown directly on the line than if starters are used. This condition arises from the fact previously mentioned that the ampere seconds and the kilowatt seconds required to start a motor are both less when the motor is thrown directly on the line than when it is started through a starter. It is true that the peak both of current and kilowatts of a single motor is greater without a starter, if we neglect the momentary peak which occurs when the motor is thrown from the starter to the line. It is obvious however that in a large factory the motors will not all be started at the same instant. The peaks of the motor starting loads will therefore not coincide and the maximum peak for the factory as a whole will in many cases be less without than it would be with starters. Certainly this will always be true for a large system. It may or may not be true for a small factory depending upon the number of units installed and their relative sizes. In a paper by P. M. Lincoln, printed in the TRANSACTIONS of the A. I. E. E. June 27, 1912, are given the results of an investigation carried out to find the effect of a starting load of induction motors upon a large power system. Mr. Lincoln investigated the case of nine large mills. The number of motors installed in the different mills varied from two to 257. The size of the motors varied all the way from very small ones to 200-h. p. In only two cases was there any excess demand either in kilowatts or in kilovolt amperes during the starting period over the running period. The two exceptions were in the case of factories in which only two and three motors respectively were installed. The biggest excess amounted to 50 per cent in kilovolt amperes and in this case the installation consisted of one 200-h. p. and one 100-h. p. motor. The results clearly indicate that in an average factory installation having five or more motors we need anticipate no peak whatever of either current or voltage during the starting period in excess of the normal full-load peak of the factory. It is true that in the cases investigated by Mr. Lincoln the motors were equipped with starters. It is evident that in view of the fact that the motors would not all be started at once that substantially the same conclusions would have been reached if no starters whatever had been provided.

Conclusions

In view of the above facts it seems clear that it is entirely practicable to dispense with starters for polyphase squirrel-cage induction motors in a great majority of cases. No harm will come to the motor. The voltage regulation of the system in a majority of cases will be just as good as it was before and will be even better in the case of large installations and the purchaser of the motors will have saved a large sum of money and will be spared a large amount of trouble due to the derangements to which starters are liable.

If it is felt that some form of starter must be used to protect connected machinery against too rapid acceleration the resistance-type starter produces rather less line disturbance, is cheaper but takes somewhat more power from the line.

It is perhaps well to add that the writer has no connection with any manufacturer of motor starters.

Appendix A

Assume that the ratio of the voltage applied to the motor to the voltage of the line is K. If the transformer used had no losses and no leakage flux, we should have

$I_1 = K\, I_m$

In which I_1 is the line current and I_m is the motor current.

Also if E_1 and E_m are respectively the line voltage and the motor voltage $E_m = K\, E_1$.

With the rotor locked, if the motor has an equivalent resistance of R and a reactance of X, the motor current will be

$$I_m = \frac{K\, E_1}{\sqrt{R^2 + X^2}}$$

and the line current will be

$$I_1 = \frac{K^2\, E_1}{\sqrt{R^2 + X^2}}$$

The wattless component of the line current will be obtained by multiplying the current by the sine of the angle of lag or

$$I_{1w} = \frac{K^2\, E_1}{\sqrt{R^2 + X^2}} \cdot \frac{X}{\sqrt{R^2 + X^2}} = \frac{K^2\, X\, E_1}{R^2 + X^2}$$

If in the resistance type starter we use a resistance R_x, such that the motor current is the same as with the transformer (giving of course the same starting torque) we have

$$I_1 = I_m = \frac{E_1}{\sqrt{\overline{R + R_x}^2 + X^2}} = \frac{K\, E_1}{\sqrt{R^2 + X^2}}$$

and as before

$$I_{1w} = I_{mw} = \frac{E_1}{\sqrt{\overline{R + R_x}^2 + X^2}} \cdot \frac{X}{\sqrt{\overline{R + R_x}^2 + X^2}}$$

$$= \frac{X\, E_1}{\overline{R + R_x}^2 + X^2}$$

But $\overline{R + R_x}^2 + X^2 = \dfrac{R^2 + X^2}{K^2}$ and

$$I_{Lw} = \frac{K^2\, X\, E_1}{R^2 + X^2}$$

Thus for the same torque developed the wattless component of the current taken from the line is the same whether a motor is started through a compensator or by means of a resistance starter, provided the compensator has no losses and no magnetic leakage. In actual practise the compensator will draw about 10 to 15 per cent more wattless current from the line than the resistance starter.

Appendix B

The curves of Figs. 6 and 7 are based upon the following data:

	Volts		Amperes		Kilowatts		
Taps	Line	Motor	Line	Motor	Line	Motor	Torque
Line	220	220	102.00	98.2	20.1	19.8	45.28
1	220	171	62.5	75.5	12.47	11.45	26.50
2	220	128	34.9	54.0	6.50	5.8	12.71
3	220	83.5	15.1	32.2	2.56	1.98	4.56

The voltages of the circuit used in obtaining these readings were well balanced. In every case the readings of all three phases were taken and the values given are the averages.

Curve 1 was obtained by drawing a straight line through the point representing 45.28 pounds-feet and 98.2 amperes. It gives the line current with a perfect transformer for the particular motor tested.

Curve 2 was plotted by using the actual torques and the line currents required to produce them.

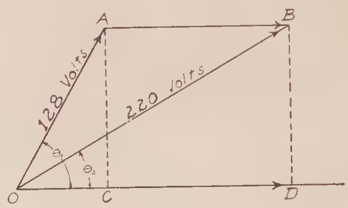

FIG. 8

Curve 3 was plotted in a similar way using the motor currents. It gives also the line current required if a resistance-type starter is used, since in this case, the motor current and line currents are equal.

The points of Curve 4 were obtained by dividing the ordinates of Curve 1 by those of Curve 2. It indicates how well the compensator performs its function of reducing the current taken from the line.

A comparison of Curves 2 and 3 will give the relative line currents taken by the auto-starter and the resistance-type starter. For large starting torques the resistance starter takes but little more current and for very great torques may even take less than the compensator.

But as pointed out it is not the line current that is of importance but the wattless component. This can be readily computed in any case. Thus, consider the data taken with tap 2.

The cosine of the angle of lag (when the compensator is used) is given by

$$\cos\theta = \frac{6500}{220 \times \sqrt{3} \times 34.9} = 0.488$$

$$\sin\theta = \sqrt{1 - 0.488^2} = 0.872$$

Then wattless component of line current = 34.9 $\times$ 0.872 = 30.4 amperes.

Fig. 8 represents the voltage relations in the case of the resistance starter. If $O\,D$ represents the phase of the current the motor voltage will lead by an angle θ_1 as shown. The drop over the starting resistance will be $A\,B$ and the applied voltage over the motor and resistance will be $O\,B$. Then

$$\cos\theta_1 = \frac{5800}{128 \times \sqrt{3} \times 54} = 0.486$$

$$\sin\theta_1 = \sqrt{1 - 0.486^2} = 0.873$$

$$A\,C = 0.873 \times 128 = 111.8$$

$$\sin\theta_2 = 111.8/220 = 0.508$$

Wattless component of line current = 0.508 $\times$ 54.0 = 27.5 amperes.

The other two points were computed in the same manner. The results show that the wattless current taken from the line with the resistance-type starter is decidedly less than with the compensator. With a perfect compensator the currents would be the same, as proved in Appendix A.

The Use of the Scalar Product of Vectors in Locus Diagrams of Electrical Machinery*

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MOST engineers interested in alternating-current apparatus are familiar with the usual representation of currents and voltages by means of vectors. Such vector diagrams are in common use in the treatment of transmission lines, transformers, alternators, etc. When the performance of a machine, say of an induction motor, varies, due to a changing load, the end of the current vector describes a curve. When this curve can be predetermined, and especially when it is a circle, the study of the performance of that particular machine is much simplified and the electrical relationships are readily visualized. Such locus diagrams are used to a considerable extent for the induction motor and for certain types of alternating-current commutator motors.

The purpose of the present article is to show the advantages of the branch of mathematics known as *Vector Analysis* in the deduction of a locus diagram, over the usual method involving plane geometry and trigonometry. The proofs are shorter and the relationship between the physical and graphical concepts is more direct. In order not to repeat the well-known theory of alternating-current motors, the present article is written with reference to Mr. John I. Hull's paper "Theory of Speed and Power Factor Control of Large Induction Motors by Neutralized Polyphase Alternating-Current Commutator Machines," A. I. E. E. JOURNAL, Vol. 39, 1920, p. 458. A number of standard diagrams will be found in his paper which can be readily proved by Vector Analysis. As a matter of fact, the present article originated as a brief discussion of Mr. Hull's paper. It is not necessary to read his paper in full in order to understand the method presented in this article, because his diagrams are used only as examples.

*Manuscript of this paper received at A. I. E. E. Headquarters, January 31, 1921.

The only concept from Vector Analysis that is needed here is that of the *scalar product of two vectors*. By definition, the scalar product of two vectors, **a** and **b**, is

$$\mathbf{a} \cdot \mathbf{b} = a\,b \cos(\mathbf{a}, \mathbf{b}) \qquad (A)$$

In this expression the letters in bold face type represent the vectors themselves, that is quantities which possess both magnitude and direction, while the letters in italics stand for the lengths of these vectors (scalar values), without any reference to their directions in the plane. Cos (**a**, **b**) is the cosine of the angle between the two vectors. The dot between **a** and **b** signifies the scalar product, or the presence of the cosine of the angle, and should never be omitted. Some authors even call the scalar product the "dot" product, to distinguish it from another product of two vectors with which we are not concerned here.

The scalar product of two vectors is a scalar quantity and has no direction. A well known example is that of a force F and of the work W done by it on a path s. The usual mode of writing is $W = F\,s\cos(F, s)$, while in Vector Analysis the relationship is simply written as $W = \mathbf{F} \cdot \mathbf{s}$. Here both **F** and **s** are vectors, while W is a scalar quantity.

From the definition of the scalar product it follows that

$$\mathbf{a} \cdot \mathbf{b} = 0 \qquad (B)$$

when two vectors are at right angles to each other. It is this particular method of expressing two mutually perpendicular vectors that is valuable in the deduction of circle diagrams of electrical machinery.

This article is also a plea for a wider use of Vector Analysis in electrical engineering, and the author hopes that other parts of this method will be found equally useful. Dr. Coffin's little book on the subject (published by Wiley's) will be found an excellent introduction to the subject, and it contains a list of more advanced works.

In the following discussion a curve, such as $M\,N$ in

Fig. 1, is referred to an origin, O, and points on the curve are defined by the variable vector $\mathbf{r}$ from the origin. Since $\mathbf{r}$ implies both magnitude and direction, no other coordinate is necessary. A given point on the curve, say P, is determined by a known vector $\mathbf{A}$ from the origin. A chord, such as $P\,Q$, is the geometrical difference of $\mathbf{r}$ and $\mathbf{A}$, or

$$\overline{P\,Q} = \mathbf{r} - \mathbf{A} \qquad (C)$$

Geometric addition or subtraction is always understood in equations which contain vectors.

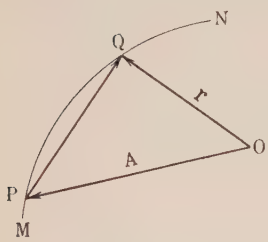

Fig. 1

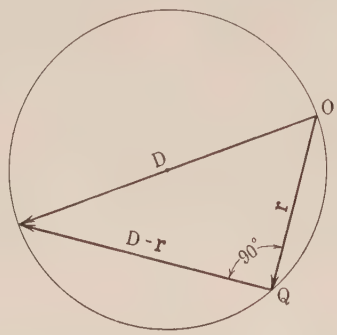

Fig. 2

The Circle Diagram

Proposition 1. Let a circle of diameter $\mathbf{D}$ (Fig. 2) pass through the origin O. For any point, such as Q, the vectors $\mathbf{D} - \mathbf{r}$ and $\mathbf{r}$ are at right angles to each other. Hence the equation of the circle is

$$(\mathbf{D} - \mathbf{r}) \cdot \mathbf{r} = 0 \qquad (1)$$

Proposition 2. L a circle (Fig. 3) be given tybe vectors $\mathbf{D}_1$ and $\mathbf{D}_2$ so as to determine one of its diameters. The vectors $(\mathbf{D}_1 - \mathbf{r})$ and $(\mathbf{D}_2 - \mathbf{r})$ are at right angles to each other; therefore the equation of the circle is

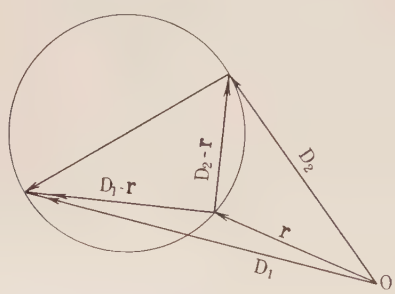

Fig. 3

$$(\mathbf{D}_1 - \mathbf{r}) \cdot (\mathbf{D}_2 - \mathbf{r}) = 0 \qquad (2)$$

These two propositions will now be applied to a proof of the circle diagram of the induction motor. In Fig. 4 the same notation is used as in Fig. 1 of Mr. Hull's paper, *viz.*, $A\,H = I_1$ is proportional to that part of the total primary flux which would be transmitted into the secondary, if the primary current were acting alone. The total primary flux, to the same scale, is proportional to $A\,I = a\,I_1$, where the primary leakage coefficient $a_1 > 1$. Similarly $H\,G = I\,E$ is proportional to the transmitted secondary flux, and $H\,D = a_2\,I_2$ is proportional to the total secondary flux, where the secondary leakage coefficient $a_2 > 1$. Using geometric addition we see that

$$a_1\,\mathbf{I}_1 + \mathbf{I}_2 = \mathbf{I}_m \qquad (3)$$

where $A\,E = I_m$ is proportional to the actual flux linking with the primary, when both the primary and the secondary circuits are excited. Neglecting the primary ohmic drop, I_m is constant and normal to the vector E_0 of the applied voltage. Similarly

$$\mathbf{I}_1 + a_2\,\mathbf{I}_2 = \mathbf{I}_s \qquad (4)$$

where $A\,D = I_s$ is proportional to the actual flux linking with the secondary, when both the primary and the secondary circuits are excited. The physical conditions in the machine are such that $\mathbf{I}_s$ is perpendicular to $\mathbf{I}_2$, that is, the only free voltage left in the secondary is used up in its ohmic drop. Thus, in vector notation

$$\mathbf{I}_2 \cdot \mathbf{I}_s = 0 \qquad (5)$$

Eliminating $\mathbf{I}_1$ from equations (3) and (4) and solving

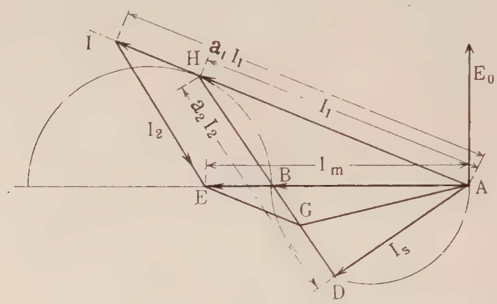

Fig. 4

the resultant equation for $\mathbf{I}_2$, we get the following vectorial relationship:

$$\sigma\,\mathbf{I}_2 = a_1\,\mathbf{I}_s - \mathbf{I}_m \qquad (6)$$

where

$$\sigma = a_1\,a_2 - 1 \qquad (6a)$$

The coefficient σ is known as the dispersion factor of the machine.

Equation (5) becomes

$$(\mathbf{I}_s - \mathbf{I}_m/a_1) \cdot \mathbf{I}_s = 0 \qquad (7)$$

Comparing this expression to equation (1) we see that point D moves on a circle, the diameter of which, $A\,B$, is in line with $A\,E$, and is numerically equal to $\mathbf{I}_m/a_1$.

To find the locus of point H, which is that of the primary current, we again use equation (5), only we now express $\mathbf{I}_2$ and $\mathbf{I}_s$ through $\mathbf{I}_1$, using equations (3) and (4). The result is

$$(\mathbf{I}_m/a_1 - \mathbf{I}_1) \cdot (a_2\,\mathbf{I}_m/\sigma - \mathbf{I}_1) = 0 \qquad (8)$$

Comparing this expression with equation (2), we see that the locus of $\mathbf{I}_1$ is a circle passing through point B, for which $\mathbf{D}_2 = \mathbf{I}_m/a_1$, and through another point on the same line, for which $\mathbf{D}_1 = a_2\,\mathbf{I}_m/\sigma$. The first point corresponds to the no-load current, the second

to that of an ideal short circuit, without any ohmic resistance.

While this problem of finding the loci of points D and H can be solved in the well known manner by elementary geometry, it has been selected as the first illustration to indicate the following two advantages of the Vector Analysis:

1. Each physical relationship is represented analytically by a definite vectorial equation.
2. The locus is determined from these equations in a straightforward manner, without the necessity of finding equal angles, similar triangles, and other geometric artifices which may or may not be apparent to the investigator.

The Effect of a Series-Connected Regulating Polyphase Commutator Motor

Proposition 3. The equation

$$[(\mathbf{F} - \mathbf{r})\, \epsilon^{j\phi}] \cdot \mathbf{r} = O \qquad (9)$$

represents a circle (Fig. 5) given by means of a chord $\mathbf{F} = O\,B$ and of the inscribed angle $90° - \phi$.

To prove this proposition, from the origin O draw the diameter $\mathbf{D} = O\,C$. For any point on the circle, such as A, we have: $\underline{/C\,A\,B} = \underline{/C\,O\,B} = \phi$, and $C\,A$ is perpendicular to $\mathbf{r}$. But $\overline{A\,B} = \mathbf{F} - \mathbf{r}$; and $A\,B$ turned to coincide with the direction of $A\,C$ is $(\mathbf{F} - \mathbf{r})\,\epsilon^{j\phi}$.

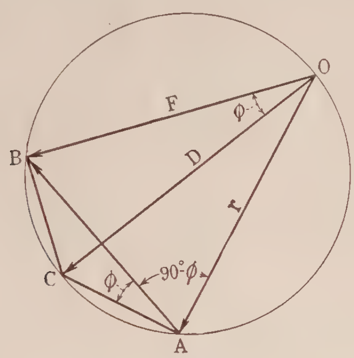

Fig. 5

Here $\epsilon^{j\phi} = \text{Cos}\,\phi + j\sin\phi$, is a factor which turns a vector by the angle ϕ. See for example the author's "Electric Circuit", p. 97. Thus equation (9) simply expresses the fact that $A\,C$ is perpendicular to $\mathbf{r}$. While the lengths AB and AC are different, this does not impair the truth of equation (9) the latter merely states that certain two directions are normal to each other. Since $B\,C = F\tan\phi$, the diameter

$$\mathbf{D} = \overline{O\,B} + \overline{B\,C} = \mathbf{F}\,(1 + j\tan\phi) \qquad (10)$$

Numerically, the diameter of the circle is

$$D = F/\text{Cos}\,\phi \qquad (11)$$

The series regulating motor possesses the two properties stated on p. 461 of Mr. Hull's paper, column 2, near the top. Let in his Fig. 6 the angle $A\,F\,G$ be denoted by ϕ, so that the secondary induced e. m. f. forms the angle ϕ with $\mathbf{I}_2$. Denoting, as before, the variable vector $A\,D$ by $\mathbf{I}_s$, the condition that $A\,F$ is perpendicular to $A\,D$ is expressed thus:

$$(\mathbf{I}_2\,\epsilon^{j\phi}) \cdot \mathbf{I}_s = O \qquad (12)$$

Using the value of $\mathbf{I}_2$ from equation (6), the preceding expression becomes

$$[(\mathbf{I}_m/a_1 - \mathbf{I}_s)\,\epsilon^{j\phi})] \cdot \mathbf{I}_s = O \qquad (13)$$

Equation (13) is of the same form as equation (9) so that the locus of $\mathbf{I}_s$ is a circle drawn upon the chord $\mathbf{I}_m/a_1$, with the inscribed angle equal to $(90° - \phi)$. Equations (10) and (11) give the diameter of the circle in magnitude and position. Equation (13) is a generalized form of equation (7). An equation similar to equation (8) may be established to prove that the locus of $\mathbf{I}_1$ is also a circle.

Just as proposition 3 is a generalized proposition 1, so proposition 2 can be generalized as follows:

Proposition 4. Let vectors $\mathbf{F}_1$ and $\mathbf{F}_2$ define the ends of a chord instead of a diameter ($\mathbf{D}_1$ and $\mathbf{D}_2$ in proposition 2), and let the inscribed angle be $(90° - \phi)$. Then from propositions 2 and 3 the equation of the circle is

$$[(\mathbf{F}_1 - \mathbf{r})\,\epsilon^{j\phi}] \cdot (\mathbf{F}_2 - \mathbf{r}) = O \qquad (14)$$

The Effect of a Shunt-Connected Regulating Polyphase Commutator Motor

The conditions shown in Fig. 9 of Mr. Hull's paper can be expressed analytically as follows: Let the vector of the resultant secondary flux $A\,D'$ be again denoted by $\mathbf{I}_s$. Then

$$\overline{A\,F} = \mathbf{I}_2\,R_2 + p\,\mathbf{I}_s\,\epsilon^{j(\frac{1}{2}\pi + \gamma)} \qquad (15)$$

Geometric addition is understood as before. $\mathbf{I}_2\,R_2$ is the secondary ohmic drop; $p\,\mathbf{I}_s$ is the induced e. m. f. of the commutator motor which e. m. f. is proportional to $\mathbf{I}_s$, and p is a coefficient of proportionality. The exponential factor turns $\mathbf{I}_s$ by the angle $(\frac{1}{2}\pi + \gamma)$. The condition that $A\,F$ is perpendicular $A\,D'$ thus becomes

$$[\mathbf{I}_2\,R_2 + p\,\mathbf{I}_s\,\epsilon^{j(\frac{1}{2}\pi + \gamma)}] \cdot \mathbf{I}_s = O \qquad (16)$$

Expanding the exponential expression, this equation becomes

$$\{\mathbf{I}_2\,R_2 + p\,\mathbf{I}_s\,[\text{Cos}\,(\tfrac{1}{2}\pi + \gamma) + j\sin(\tfrac{1}{2}\pi + \gamma)]\} \cdot \mathbf{I}_s = O$$

The last term containing $j\,\mathbf{I}_s$ represents a vector perpendicular to $\mathbf{I}_s$; hence its scalar product with $\mathbf{I}_s$ is equal to zero, and may be omitted. Instead of Cos $(\pi/2 + \gamma)$ we can write—Sin γ, and the preceding equation becomes

$$(\mathbf{I}_2\,R_2 - p\,\mathbf{I}_s\,\text{Sin}\,\gamma) \cdot \mathbf{I}_s = O \qquad (17)$$

Substituting the value of $\mathbf{I}_2$ from equation (6) we finally get:

$$\left[\mathbf{I}_m \frac{R_2}{a_1\,R_2 - p\,\sigma\,\text{Sin}\,\gamma} - \mathbf{I}_s\right] \cdot \mathbf{I}_s = O \qquad (18)$$

where σ is defined by equation (6a).

Comparing this expression to equation (1) we see that the locus is a circle, and the first term gives its diameter. When the commutator motor is not in the circuit, that is when $p = 0$, equation (18) becomes identical with equation (7) and gives the ordinary circular locus of the induction motor.

Discussion at Midwinter Convention

ELECTROMAGNETIC FORCES; A PROPOSED REVISION OF THE LAWS[1]

(HERING), NEW YORK, N. Y., FEBRUARY 16, 1923.

ELECTROMAGNETIC THEORY AND ITS BEARING ON THE PINCH AND STRETCH PHENOMENA

C. O. Mailloux: The features of commanding interest in Dr. Hering's paper are the "pinch" and "stretch" phenomena, both discovered by him; and the difficulty of explaining these phenomena by the existing theories of electromagnetic fields is what has led Dr. Hering to urge the revision of these theories.

The discussion of the paper must, at the outset, recognize the polemic situation due to the very interesting and significant circumstance of the apparent antagonism to the paper, which has resulted from the necessity of questioning the completeness and adequacy of certain theories, notably those of Maxwell, in regard to electromagnetic fields, because, as will be seen, the limitations of Maxwell's theories are of the greatest importance in this case. It is as if it was not known that flaws have been found, even in great numbers, in Maxwell, years and years ago, and by men who were Maxwell's peers,—Hertz, Henri Poincaré, Helmholtz, Heaviside, Bjerkness, etc. When facts and theories fail to agree, the theories usually have to yield ground in the end. It is the speaker's opinion that the facts have the best of it in this case.

It seems hard to believe that any teacher could expect unquestioning faith in Maxwell today, in the light of the commentaries and revisions made by the men just named, to mention no others. For over twenty-five years Maxwell's treatise, though a great classic, and a valuable work of reference, has been obsolete as a text book, and as a means of presentation of Maxwell's own theories. The reasons for this were made very clear by the very man—Hertz—whose research work on electric waves supplied experimental evidence of the accuracy of Maxwell's electromagnetic theory of light, and helped to prove that theory.[2] Hertz's two papers on the "Fundamental Equations of Electromagnetics," published in *Wiedemann's Annalen*, in 1890, (and which constitute Chapters XIII and XIV of the English translation published in 1893), were an attempt to simplify and clarify Maxwell's equations and to make them more consistent with Faraday's fundamental idea that the "field of action" of energy was an intervening medium known as the ether. As Hertz put it, Maxwell frequently wavered between the conceptions that he found in existence and those at which he arrived himself. Hertz points out that between the concept of direct action at a distance, springing across space, and the concept of an action which is propagated from point to point in a hypothetical medium, four distinct methods of reasoning and mathematical treatment can be distinguished, and that Maxwell, in different parts of his treatise, leans towards two of these modes of thought, each involving a different conception of "electricity." He says: "And so, unfortunately, the word 'electricity,' in Maxwell's work, obviously has a double meaning." After giving the two meanings, he adds: "If we read Maxwell's explanations and always interpret the meaning of the word 'electricity' in a suitable manner, nearly all the contradictions which at first are so surprising can be made to disappear. Nevertheless, I must admit that I have not succeeded in doing this completely or to my entire satisfaction."

1. A. I. E. E. JOURNAL, 1923, Vol. XLII, February, p. 139.

2. Although Hertz was one of the first workers in this field, his first experimental determinations of the velocity of propagation of electromagnetic waves gave erroneous results—only about 200,000 km. per second (instead of 300,000)—which threw serious doubt upon the correctness of of Maxwell's equations. Blondlot, in France, was the first physicist to obtain experimental results by two independent methods that were in complete accordance with Maxwell's theory. Hertz' experiments confirmed these results subsequently.

Poincaré expressed a similar opinion in his discussion of Maxwell's theories in Vol. I of his "Electricité et Optique." Also see on this point Poincaré's "La Science et l'Hypothése," page 250 and page 259.

While Maxwell is always given the highest credit by all authorities for the marvelous gigantic work done by him as a pioneer in the development, formulation, and demonstration of new theories and principles, it is admitted generally that his work was not so complete and perfect as to require no ulterior revision or modification.

The work of revision of Maxwell's equations was begun as early as 1885 by Heaviside, and the importance and value of Heaviside's contributions are admitted by all those who have participated in the work since then. For twenty years or more it has been considered necessary, in order to obtain a complete understanding and a satisfactory interpretation of Maxwell's theories, to discard Maxwell's own methods, and to resort to more modern methods of presentation which include the ideas of Heaviside, of Hertz, Poincaré and the other eminent authorities who have gone into the subject exhaustively. The study of Maxwell without the guidance of these authorities is apt to be misleading and harmful. Admiration of the magnificent structures erected by the genius of Maxwell does not make it a duty for his admirers to close their eyes to certain defects in these structures, or to insist upon their being also acknowledged as perfect anyhow. We would not proceed far before realizing the absurdity of such a policy.

Thus, Hertz has called attention to rudimentary ideas of a physical and of a mathematical nature ("vector-potential," being cited as an example of the latter), used by Maxwell, which are now regarded as being superfluous and really encumbering scaffolding. He says, significantly, that there is no object in replacing the *forces* themselves by *potentials* unless a mathematical advantage is gained thereby. He sees no such advantage in the introduction of the vector-potential in the fundamental equations; and he adds:

"Furthermore, one would expect to find, in these equations, relations between the physical magnitudes which are actually observed, and not between magnitudes which serve for calculation only."

It is for such reasons that vector-potential has been eliminated altogether, and that other concepts have been modified in the modernized form of Maxwell's equations.

Having thus brought out the now recognized fact that Maxwell's work was *not* invulnerable, but that it *was* weak in spots, and has had to be retouched, we may next consider the fundamental limitations of the Maxwellian theory, to see if perhaps too much has not been expected of it.

Poincaré, the peer of all his contemporaries in pure and applied mathematics, and the greatest genius of all time in mathematical philosophy and logic, said:

("La Science et l'Hypothése," page 249):

"Maxwell does not give a mechanical explanation of electricity, and of magnetism.

He merely shows that such an explanation is possible."

The notes obtained from some courses of lectures on Maxwell's theories presented in the revised form above mentioned, which the speaker attended many years ago, as a graduate student, contain the following interesting commentary:

"It should be stated and understood at the outset that the Maxwellian theory does not tell us anything of the true ultimate nature of electricity and magnetism, or of electromagnetic processes. What it tells us is how certain vectors, namely, vectors of electric and of magnetic force and flux, vary in space and in time. It furnishes a fairly complete *geometrical* theory of the space and time relations of these vectors and of the forces

or fluxes which they represent. While it tells us of these things to a satisfactory degree of completeness, it gives us only limited information—satisfactory as far as it goes, but not going far enough—regarding the *dynamic* theory of these forces and of the phenomena in which they are involved."

These views were confirmed and corroborated in convincing manner by Prof. V. F. K. Bjerknes, in his lectures on "Fields of Force" delivered at Columbia University in 1905, which the speaker attended. In his introductory remarks (See the printed account of these lectures, Publication One of the E. K. Adams Fund for Physical Research, *Columbia University Press*, 1906), Prof. Bjerknes said:

"The idea of electric and magnetic fields of force was introduced by Faraday to avoid the mysterious idea of an action at a distance. After the victory which Maxwell's theory gained through the experiments of Hertz, the idea of these fields took its place among the most fruitful of theoretical physics. And yet if we ask, what *is* an electric or a magnetic field of force? No one will be able to give a satisfactory answer. We have theories relating to these fields, but we have no idea whatever of what they *are* intrinsically, nor even the slightest idea of the path to follow in order to discover their true nature. Above all other problems which are related to fields of force, and which occupy investigators daily, we have, therefore, the problem of fields of force, namely, the problem of their true nature."

The method of research followed by Prof. Bjerknes consisted in generating what he termed "*hydrodynamic*" fields of force in masses of water by means of motion of vibratory nature, produced by pulsating and oscillating bodies, and then tracing analogies between the phenomena of attraction and repulsion produced in these "hydrodynamic" fields and those produced in electric and magnetic fields. By means of beautiful experiments he showed that the lines of magnetic force in a magnetic field can be represented in perfectly analogous manner by lines of oscillation in a hydrodynamic field. The hydrodynamic field experiments produced phenomena resembling magnetic attraction and repulsion so closely as to suggest a very close analogy, if not an identity, between the physical principles involved in both cases; and explanations of electric and magnetic phenomena were sought by the aid of these analogies. It was found, however, that the analysis and interpretation of the phenomena was much less difficult in the case of the hydrodynamic field than in the case of the electric and magnetic fields. Prof. Bjerknes says:

"The extent of our knowledge of the different kinds of fields differs greatly. All the properties of the hydrodynamic fields follow directly from the most trustworthy laws of nature, that is from the principle of the conservation of the mass, and from the principles of dynamics. With reference to electric or magnetic fields, on the contrary, we have only formal theories. First we have an extensively developed *geometric theory of the distribution in space of the vectors*, which describe the field. And then, in a more or less superficial connection to this geometric theory, we have a very much less developed theory of the dynamic properties of the fields.

Taking the facts as they lie before us, we shall be obliged, therefore, to give to our theory a dualistic form, comparing separately the geometric and the dynamic properties of the two kinds of field. It may be reserved for the future to penetrate to the central point, where the geometry and the dynamics of the question are perfectly united, and thus make the comparison of the two kinds of field perfectly easy."

In reference to the dynamics of the electric or the magnetic field he says:

"Our knowledge of the dynamics of the electric or magnetic field is very incomplete, and will presumably remain so as long as the true nature of the fields is unknown to us.

"What we know empirically of the dynamics of the electric or magnetic field is this:—bodies in the fields are acted upon by forces which may be calculated when we know the geometry of the field. Under the influence of these forces the bodies may take visible motions. But we have not the slightest idea of the hidden dynamics upon which these visible dynamic phenomena depend."

Faraday's idea, for instance, of a tension parallel to, and a pressure perpendicular to the lines of force, as well as Maxwell's mathematical translation of this idea, is merely hypothetical. And even though this idea may contain more or less of the truth, investigators have at all events not yet succeeded in making this dynamical theory a central one, from which all the properties of the fields, the geometric, as well as the dynamic, naturally develop, just as, for example, all properties of hydrodynamic fields, the geometric as well as the dynamic, develop from the hydrodynamic equations. Maxwell himself was very well aware of this incompleteness of his theory, and he stated it in the following words:

"It must be carefully borne in mind that we have only made one step in the theory of the action of the medium. We have supposed it to be in a state of stress but have not in any way accounted for this stress, or explained how it is maintained. I have not been able to make the next step, namely, to account by mechanical considerations for these stresses in the dielectric."

In spite of all formal progress in the domain of Maxwell's theory, these words are as true today (1905) as they were when Maxwell wrote them.

In reference to the geometric properties of electromagnetic fields according to Maxwell's theory, Prof. Bjerknes says:

"Our knowledge of electromagnetic fields is contained in what is generally called Maxwell's theory. This theory does not tell us what electromagnetic fields are in their true nature. It is a formal theory, bearing upon two aspects of the properties of the fields. What are called Maxwell's equations give a very full description of the variation from time to time of the geometric configuration of electromagnetic fields. To this geometric theory is only feebly linked the much less developed theory of the dynamical properties of these fields."

In reference to the geometric description of electromagnetic fields, Prof. Bjerknes says:

"To give this description, a series of special electric and special magnetic vectors has been introduced.

"We believe that these vectors represent real physical states existing in, or real physical processes going on in the medium which is the seat of the field. But the nature of these states or processes is perfectly unknown to us. What still gives them, relatively speaking, a distinct physical meaning is, as we shall show more completely in the next lecture, that certain expressions formed by the use of these vectors represent quantities, such as energy, force, activity, etc. in the common dynamical sense of these words. These quantities can be measured in absolute measure. But their expressions as functions of the electric or magnetic vectors contain always two quantities of unknown physical nature. When once the discovery of a new law of nature allows us to write another independent equation containing the same unknown quantities, we shall be able to define perfectly the nature of the electric and magnetic vectors, and submit them to absolute measurement in the real sense of this expression. Provisionally, we can only do exactly the same as does the mathematician in problems where he has more unknowns than equations; viz. content ourselves with relative determinations, considering provisionally one or other of the unknown quantities as if it were known. But we retain the symbols for the unknown quantities in all formulas bearing upon the pure theory of electromagnetic phenomena, for this will be the best preparation for the final solution of the problem."

"This imperfect knowledge is, of course, also the reason why our theory of electromagnetic fields is split into two different, loosely connected, parts; first the geometric theory of the fields, where the relation of the vectors to time and space is considered

independently of every question of the physical sense of the vectors; and, second, the dynamical theory of the fields, where the question of the nature of the vectors is taken up, but only imperfectly solved."

If we bear in mind the obviously electrodynamic nature of the new phenomena mentioned in Dr. Hering's paper, and for which the classic laws of electromagnetism fail to give an adequate explanation even when they are strained by more or less sophistic expedients (sliding contacts), we can appreciate the force of the preceding comments of Prof. Bjerknes upon the limitations of Maxwell's theories from the electrodynamic point of view. Indeed, in the opinion of the speaker, the burden of proof may be considered as having been thrown back upon the Maxwellites, meaning those of the orthodox school, because the Maxwellites of the reformed school would have been less militant, precisely because they are informed in regard to the flaws, the gaps, and the weak joints in electromagnetic theory as it stands today. It is dangerous in physics, as in other things, to claim more than the physical facts will warrant. The true office of physical laws is to explain physical facts and not to contradict them or deny their possibility.

The reference made by Bjerknes to Faraday's idea of a tension parallel to, and a pressure perpendicular to, the lines of force in a magnetic field, indicates that he attached much importance to further development of a dynamic theory based upon that idea, in a manner that would make it possible, as he says, for *all* the properties of magnetic fields, both *geometric* and *dynamic*, to be developed *naturally*. Dr. Hering comes very close to Bjerknes when he expresses the belief that a satisfactory theory could be based on the assumption of only a single magnetic force, the tension along a line of force, the other property, the repulsion of like lines, being then deduced from the first.

Unfortunately, this is easier said than done. We may see the goal that it is desired to reach, but as Bjerknes well said: "We have not even the slightest idea of the path to be followed in order to attain it."

The trouble appears to be that the specification of the physical characteristics and properties of magnetic fields is not yet complete. That is why, as Bjerknes says, we have more unknown quantities than equations. Nevertheless, Dr. Hering's paper contains many suggestions and cautions that will prove of great value, as a means of keeping on the right track whenever we do succeed in finding an entrance to the right path. The paper is filled with ideas, the complete discussion of which, in some cases, would lead us far into physical and philosophical problems of more or less abstruse character.

With regard to the stretch phenomenon, which seems to be the principal cause of objection to Dr. Hering's views, it may surprise those who dispute its existence and even its possibility on Maxwellian or other theoretical grounds, to learn that two very distinguished disciples of Maxwell, Mascart and Joubert, disagree with it very seriously. This may be due to the fact that the treatment of electromagnetism in their own celebrated classical treatise on "Electricity and Magnetism" does not follow Maxwell very closely, but follows more the French School of Physics. In Volume I, Part IV, Chapter I, Paragraph 455, after the statement that "the action of a current upon itself, can also produce deformations or continuous motions," some experiments with a movable portion of circuit are described; and the discussion ends with the following significant remark: "If the wire is elastic it will *stretch* until its elasticity balances the electromagnetic forces."

This may be considered expert opinion of highly qualified and competent character in defense of Dr. Hering's views.

Dr. Hering's suggestion that the mathematical theory should avoid integrations around complete circuits and should, instead, be based upon limited portions or elements of circuits, is of great importance. He sees the same dangers in going too far, or beyond proper limits, that occurs in the case of the mathematics of the soap bubble film, mentioned in the paper, in which a formula that is quite rational for finite values of the radius of the buble, becomes "insane" when the radius is increased to infinity. This is a matter of such importance, and similar cases of mathematical insanity are so frequent, that it is worth while to call attention to the simple means of preventing it, namely: "*Beware of absolute infinity*," "*No thoroughfare here.*" That is perhaps the first thing that every student of mathematical physics should learn by heart. It is the one and only unfailing preventive of that form of insanity. It may be consoling to learn that many of the greatest mathematicians that the world has known were not free from attacks of that form of insanity; but that is no excuse for not taking measures to stamp out the disease.

Ask any student to draw two right lines, one perpendicular to the other, at or near its middle, and then to imagine both lines to be prolonged indefinitely; and ask him if he can possibly conceive that as the two lines were increased in length, there is at any stage even a faint resemblance of the *T* to a sector of circle. He will say "no." Let him, now, start with a small sector of circle, and let him imagine the radius of the circle to be increased indefinitely; and then ask him if, ultimately, the arc of the circle will become a right line. The chances are that he will answer "yes;" although the correct answer should be: "There can be no circle whose periphery is a perfectly right line." What is the reason for this error? In the first example, the mind was left free to see and to reason; in the second example, the mind was hypnotised by a question which assumed the possibility of doing something that is impossible physically, metaphysically, and mathematically, for human beings, namely, the crossing of the abyss that extends from the limits of the finite to the infinite. That impossible kind of circle *is the hypothetical* "circle of Pascal" whose center is everywhere and whose circumference is nowhere. The limit of the finite is only a *relative* infinity. The other is an *absolute* infinity. The relation between these two kinds of infinities has been treated exhaustively in the work of Henry Fleury ("Théorie rationelle de l'Infini mathématique et du Calcul Infinitesimal," Paris 1899, pp. 324). Under the heading of "Properties of Infinity" we read: "Infinity has no other property than that of being *impossible. Any calculation based upon absolute infinity, or upon any function whatever of absolute infinity, is itself absurd.*"

The following quotations are of interest:

"In analysis as in geometry, I distinguish between two infinities; one which I term absolute infinity, is impossible; the other, which I term relative infinity, consists of a very large fictitious value which is assigned to a variable."

"To tell the truth, *there is no infinity in mathematics*; *Because absolute infinity is impossible, and relative infinity is essentially finite,* since it is a very large value assigned to a variable. Hence, mathematics, like the infinitesimal calculus, could get along without it perfectly. Just as the harm does not consist so much in believing in witches as in burning them, so the harm does not consist so much in admitting the existence of infinite quantities as in attributing fantastic properties to them. I concede to absolute infinity only the property of being impossible. *As for relative infinity, since it is essentially finite, it will have all the properties of finite quantities, and it will have no other properties.*"

"Whenever, in mathematics, we come up against a stumbling-block, a scandal, or a paradox, you can ask *where the infinity is*: I mean to say that the error is the result of attributing some false property to infinity, which, I repeat, has no other property than that of being impossible. . . . . . .

Since absolute infinity is impossible, any property assigned to it, any operation performed upon it, will be absurd. On the contrary, since relative infinity is essentially finite, it will have the same properties and it will be subject to the same operations as finite quantities. It follows that any property which does

not apply to finite quantities cannot apply to either absolute infinity or relative infinity. I therefore declare absurd any reasoning which assigns to infinity a property that does not also apply as well to finite quantities."

"The distinction between the two infinities (absolute and relative) exists in geometry as in mathematical analysis; hence, if by an infinite right line we mean, a right line having no ends, it is absurd and impossible; but if we mean a right line which is extremely long with respect to others that are considered finite, it will still have ends and it will in reality be finite; it will be a relative infinity.

Likewise, since every plane necessarily ends at a line which is its contour, then if by the term plane, we mean a plane deprived of this contour, or perimeter, it is absurd and impossible. But if we mean an extremely large plane, bounded like any other plane, by its perimeter, it will, in reality, be a finite plane. If we call it infinite, it will be a *relative infinity*. An infinite right line which has ends can be doubled or tripled in length. A right line having no ends, being an impossibility, it cannot be lengthened or shortened.

In geometry as in mathematical analysis, the general properties of finite magnitudes apply to infinite magnitudes, when we mean relatively infinite. But if we mean an absolutely infinite magnitude, or one without limits, it is impossible and absurd, and so is any property that may be assigned to it.

The *circle of Pascal*, whose center is everywhere and whose circumference is nowhere, is an absurd infinity. The same would be true of a square whose center would be everywhere, and whose perimeter is nowhere. It is not necessary to inquire which is the most round or the most square of these figures. Any comparison would be absurd."

We can now see clearly enough why the formula for the tension of a plane soap bubble film gives infinity, which is not true, as Dr. Hering says. According to Fleury, the very idea of attempting to use such a formula with any infinite values is absurd, and the alleged result is simply impossible from every point of view.

It is easy to reach equally absurd and impossible conclusions in electrodynamics, and, for example, to ascribe infinite values to the magnetic flux around a conductor under conditions where we know and can demonstrate experimentally that the flux decreases with the distance from the conductor. In one case, it was actually contended that the magnetic flux, though decreasing until it was less than any assignable value at "relative" infinity, suddenly jumped to an infinitely great value when "jockeyed" across the abyss between relative and absolute infinity. This wonderful acrobatic performance was indeed taken, in some cases brought to the speaker's attention, as evidence that Hering must be wrong and Maxwell must be right. It is to prevent such fool jumps that the signs "Beware of absolute infinity," "No thoroughfare here," should be ever present in the mind's eye of mathematical physicists, especially those of the amateur class.

Dr. Hering's idea of using a counter e. m. f. generated somewhere in the circuit as a criterion and a measure of mechanical motions appears acceptable, but it does not tell *where* or *how* the motions are produced; it gives the end-result without definite information in regard to the path, agency and process by which this result is reached.

His idea that "the flux around a conductor or magnet should be pictured as though it were in some way elastically attached to the material in which its source lies," would be acceptable if there was not some doubt left as to his precise meaning by the statement previously made to the effect that "it seems to be much better to consider the magnetic field around a current-carrying conductor to be merely an action at a distance, *as Faraday proposed*, the seat and source of the force being in the material of the conductor and not in the space around it." Now the very thing that Faraday denied consistently was the possibility of action at a distance under any circumstances. The reference to hydrodynamic action made further on by Dr. Hering shows that he himself has realized the necessity of an intervening medium having the physical properties of a fluid. In a previous paper on "A New System of Electromagnetic Forces Needed" (A. I. E. E. April, 1922, Vol. XLI, No. 4, pp. 305-307), reference was made to "hydraulic action in the ether" as a possible explanation of the "pinch" and "stretch" phenomena.

The speaker finds himself at variance here with Dr. Hering's views.

The speaker has believed for more than forty years, and he is still of the opinion that actions and reactions of elastic character play a role of paramount importance in electromagnetic phenomena. In his opinion, a liquid having merely *hydraulic* properties and characteristics can exhibit some of the mechanical or dynamical, (let us rather say *physical*) properties and characteristics of magnetic strains and stresses, but it cannot exhibit them all. Indeed, some of the phenomena observable in magnetic fields indicate *rigidity*, *stiffness* and *springiness*, which are properties that only certain metals, (e. g. tempered steel), can exhibit, and which no liquid of any sort can even approximate.

Just forty years ago, the speaker, then a very young man, delivered an experimental lecture before the New York Electrical Society on "Action and Reaction in Magnetic Fields." The condensed report of the lecture, which appeared in the *Electrical World* of March 10th, 1883, was prepared by the lecturer himself, who was then the editor of that publication. The lecturer mentioned, among other things, an interesting new property of lines of magnetic force observed by him a few years before (1879) in the course of an experimental study of magnetic fields, namely, the property of *resiliency* or *rebound*, under certain conditions.

The following is an extract from a reference to the lecture and to the property in question contained in the A. I. E. E. TRANSACTIONS (Vol. VI, 1889, pp. 288, 289):

"I have believed in the theory of the elasticity of lines of force for some years. I employed the term resiliency in my lecture, and I still adhere to it as being, in my opinion, somewhat more appropriate, and I have believed, for a long time, that when the mathematical theory of elasticity shall have been developed to a sufficient point, we shall have all of the data necessary for working out a perfect theory of magnetism. In other words, I believe that magnetism is nothing more than a manifestation due to the elasticity of the surrounding medium, that it is an elastic disturbance, and I may state, in passing, that it is here that I differ with the conception advanced by Faraday and Prof. Thomson as to the shortening of the lines of force. I think that the idea of shortening is rather vague. I hardly think that we can say that lines of force shorten as such. It would probably be more appropriate to express it in some other way. What seems to us to be shortening is probably merely the manifestation of some other phenomenon. Another point is the snapping of the lines of force. I shall endeavor to present some experiments which illustrate the fact that lines of force do snap and break, as I did in the lecture of 1883, and that the snapping is not simultaneous."

These remarks would need very little modification today, so far as their *substance* is concerned. They might be amplified somewhat so as to make clear what were (and are still) the speaker's views in regard to the so-called "shortening" of lines of magnetic force. There was also a slight error in saying that lines of magnetic force "break" without explaining more fully what was meant. The fact is that lines of magnetic force do not "*break*" in the sense of being severed or parted like a string or a wire that is broken into two pieces; but they may *break away* and be parted from an "anchorage" such as from an iron armature which is moved in front of the poles of a magnet

or in any magnetic field. That "break away" movement is sudden or "snappy," but it does not occur simultaneously for all the lines of force in a given portion of magnetic field; it occurs for each "vortex" by itself when the conditions are right for that vortex or line of force.

The additional details promised were not sent in, partly from lack of time, but mainly from a realization of the importance of reviewing the whole subject fully before adding to the extempore discussion referred to.

The earliest conjectures of the speaker, as outlined in 1879 (in the unpublished paper mentioned in the previous A. I. E. E. discussion) are not without interest on this occasion, when it is desirable to gather together all ideas that may prove helpful. These conjectures were:

That lines of magnetic force were elastic like steel rings or hoops; that they tended, normally, in a homogeneous diamagnetic medium, to take the form (figure) of perfect concentric circles; that any departure from the circular concentric form was, in a sense, abnormal, being due to disturbing conditions and forces, and that it was always attended by reactions which tend to restore the circular form; that there was a limit to the extent to which they could be swerved or distorted from the circular form; and that, at the limit of distortion, they would "break away" and assume a more circular ("normal") form, and would do so in a sudden, snappy manner as if they were *resilient*, and recoiled like an elastic ring that has been distorted and is suddenly released or else suddenly breaks loose from the distorting force that was acting upon it.

The process of reasoning followed was as follows:

If a hoop made of tempered steel wire forming a perfect circle is distorted in any way and then released suddenly, it will instantly recover the form of a perfect circle. A perfectly elastic steel hoop would be a good physical model of a line of magnetic force or of a bundle or coil of such lines, in regard to the manner in which it is influenced by, and reacts upon, outside forces; but such a model is incomplete and inadequate for the representation of the reactions which the magnetic field itself exerts upon the forces producing it. According to Newton's principle, dynamic action and reaction are always equal and opposed to each other. On the theory that, in this case, an elastic disturbance is produced in the ether surrounding an electric conductor, a line of magnetic force may be regarded as being a dynamic *reaction* against some dynamic *action* which is exerted by the electric current passing through the conductor If we picture the action at each line of force as comparable to that of a conical wedge which is forced into a rubber ring, then the *reaction* is made intelligible to us as a state of tension which causes the ring to be stretched into a larger, thinner ring; and the tension thus produced is the complete measure of both the reaction and the action. If the action is increased, the reaction will increase enough to balance the action and the rubber ring will be expanded into a still larger circle. If the action decreases, the ring will shrink in size until the decreased reaction in the new state of stretch balances the reduced action. This is what the speaker had in mind when he said (in the A. I. E. E. discussion in 1890) that we can hardly say that lines of force shorten as such, and that the shortening is probably the manifestation of some other phenomenon. The phenomenon which he had in mind was the *elastic reaction of the medium* against the action of the current producing the lines of force. In this case, the "action" is, in all probability, different from that represented by a mechanical pressure exerted radially like the pressure exerted by the conical wedge above mentioned; and, consequently, the reaction is entirely different from that represented by the tension of a stretched rubber ring. The speaker early acquired the habit, which he has never lost, of using elastic steel rings as a mechanical model or analogy in explaining magnetic action. Thus in a note-book under date of August 11, 1889, we have:

Theory of Magnetic Attraction and Repulsion (based on experiments of 1879), (with two diagrams):

"Taking two conductors parallel to each other and carrying currents, as the simplest illustration, we have:

1st, attraction when the currents are in the same direction;

2nd, repulsion when the currents are in contrary directions.

(1) In the first case, I regarded the attraction as due to the blending of the magnetic circuits into one circuit, as shown in the sketch, and the effort made by the resultant circuit to assume the concentric circular form. In other words, when there is only one conductor it tends to maintain itself in the center of the vortex; when there are two or more they tend to go to the center of a combined or resultant vortex, and consequently to come together.

In such a case I can conceive that, instead of being shortened, some of the lines immediately surrounding the conductors, might be on the contrary actually stretched or distended. In fact, they would all be in a sense stretched as long as the vortex did not resume the perfect circular form.

(2) The second case (of repulsion), I regarded as that of the compression of a steel hoop or ring, by contact with another steel hoop or ring, with the conductor impelled as before to maintain itself central with respect to the rings, and being consequently, urged in a direction opposite from attraction. In this case, we might consider that the lines of force act rather by expanding than by contracting or shortening."

In a note made the next day, the concept of a vortex-like disturbance of the ether is introduced.

The vortex-motion theory always was interesting to the speaker largely because it is a *kinetic* theory. He believes, with Maxwell, Shelford-Bidwell, and others, that kinetic theories of magnetism are the only ones that will stand serious scrutiny. Even in a medium which is infinitely tenuous like the ether, kinetic energy can still be developed in measurable quantities, since the decrease in mass can be made up by an increase in velocity. In the formula $E = m v^2/2$, the value of E will remain constant as long as the product $m v^2$ remains constant, and when the mass (m) is reduced to $1/n$ of its value, the velocity (v) does not have to be increased n times but only the *square root* of n times. Now the elastic properties that make lines of magnetic force act as they do are just such as might be expected to result from kinetic reactions in which the mass is very small but the velocity very great. It is interesting to note in this connection that the speaker succeeded in making vortex rings of the kind known as "*smoke rings*" exhibit the phenomena of attraction and repulsion which are illustrated in the two diagrams (in the note of August 11, 1889). He has made two smoke rings coalesce into a single larger ring which tended immediately to assume the figure of a larger circle; and he has made smoke rings repel each other exactly in the manner indicated in the note. Although the real physical character of the "action" and of the "reaction" are not yet (and may never be) definitely known to us, we are, nevertheless, justified in describing the characteristics of the reaction as comparable to those of an elastic disturbance. Things which are equal to the same thing are equal to each other, in mathematics; and in mathematical physics, they can be treated as if they were equal to each other, and they can be substituted for each other. Therefore, even if, in the end, we should have to modify our views as to the *causes*, we are not likely to be obliged to revise them in regard to the *effects*.

The "pinch" and "stretch" phenomena were regarded at the outset by the speaker as being merely natural and logical consequences of the "theory" of magnetic action which he had built up for his own private use, so to speak. To his mind, the pinch effect was an elastic *reaction*, *equal* and *opposed* in its effect to the *action* of a force produced by the electric current passing through the conductor. He looked upon the action as being comparable to a pressure applied to the inside of a cylinder made of an elastic substance possessing some peculiar properties, such as he conceived might be exhibited by vortex motion of quasi-infinitely great velocity, in matter of quasi-infinitely small

mass; and he pictured the reaction as comparable to the stress or tension produced in that elastic substance. He did not picture the substance, as Dr. Hering did, as one having the characteristics of a liquid, because his study of the subject had taught him that the characteristics implied physical properties like *stiffness*, *strength*, *elasticity*, *resilience*, which recall *steel* and other metals. Kelvin, years ago, in presenting the undulatory theory of light, postulated the existence of a transmission-medium having, at times, the properties of *jelly*, and, at other times, the properties of a rigid but elastic solid like steel.

The speaker's views in regard to the nature of magnetic action makes him feel warranted in reasoning about the outward physical effects produced in a magnetic field as if these effects were not only *analogous* but *equivalent* to an elastic disturbance in a medium where kinetic energy is developed which is due less to *mass* than to *velocity* (as in the case of a vortex-ring). (A vortex-ring illustrates a condition where elastic and resilient properties are due to velocity-effects). To his mind, the "stretch" effect seems as natural and as reasonable as the "pinch" effect, being merely the same "reaction" manifesting itself against the "action" in an axial direction. In other words, it seems reasonable to him that the reaction should manifest itself physically by a tendency not only to *pinch* but also to *stretch* the conductor carrying the current which produces the magnetic field around that conductor.

The preceding considerations show why the author does not support the idea of hydraulic action in the ether, while believing strongly in the idea of elastic actions and reactions. The author's "conjectures" of 1879, have rendered good service on many occasions as the basis of a working theory, in making clear many phenomena and facts about magnetic fields. Seeing the difficulties that seem to confront all other working theories in regard to "action and reaction in magnetic fields" in spite of the efforts made in the last forty years, the speaker has been wondering if, perhaps, the "conjectures" could not be utilized to a good purpose in other attempts to revise and extend the present theories.

V. Karapetoff: In discussing this paper it is necessary to use certain well established laws of mathematical electricity. I will write them down, so as to make it clearer as to what the controversial matter is. One of the established laws of electro-magnetism is that the stored energy in a circuit without iron is equal to one-half the square of the current times the co-efficient of inductance, or $W = 0.5\, i^2 L$. This may be taken as the definition of inductance as well, so that if you know the energy and the current in the circuit, you can compute L. The same coefficient L is sometimes defined from the induced e. m. f. as $E = - \hat{L}\, d\, i / d\, t$. All this is not a controversial matter, but that of definitions. Now we come to the fundamental law of mechanical forces which law is somewhat assailed in the paper. In the first place, Maxwell himself gives credit for this law to Lord Kelvin, referring to Nichols *Cyclopaedia of Physical Science*, edition of 1860, so that that is not Maxwell's Law, but Lord Kelvin's Law. It is rather surprising that in the paper under discussion, Kelvin, the originator of the law of electro magnetic forces is not mentioned at all. This law applies specifically to a constant current and no iron must be present. Consider a small deformation in space and impose the condition that the current during this deformation remains constant. The circuit is such that a part of it is flexible, or has a sliding contact. What are the energy relations during this small displacement? Lord Kelvin's answer is that the energy brought from the external source, let us say from a battery, is twice as great as is necessary to perform the mechanical work. The excess goes to increase the stored energy of the circuit. I have repeatedly called attention to this law in some previous volumes of our TRANSACTIONS, for instance, in the discussion on the opening of disconnecting switches on short circuit, on stresses in bus-bars, and so forth. The last chapter of my "Magnetic Circuit" is devoted to the subject of mechanical forces in a magnetic field, to which chapter I refer for proofs.

With a constant current, the infinitesimal energy brought from the source of current is $d\, W_1 = i^2\, d\, L$, since it is equal to the change in electromagnetic linkages. The increase in the stored energy is $0.5\, i^2\, d\, L$. Hence, the energy converted into mechanical work, equal to the difference of the two, is

$$F\, d\, s = 0.5\, i^2\, d\, L$$

Therefore, the mechanical force is

$$F = 0.5\, i^2\, (d\, L / d\, s)$$

where s is the direction of the virtual displacement. It may also be of interest to state that the coefficient of self-inductance may be conveniently represented in the form

$$L = n^2\, P_{eq}$$

where n is the number of turns and P_{eq} is the equivalent permeance of the magnetic circuit (Magnetic Circuit, p. 184).

I shall limit myself to one feature of Dr. Hering's paper, namely that of mathematical relationships which are entirely independent of our ideas or pictures as to what electro-magnetic phenomena are. Even if our physical conceptions should be radically changed tomorrow, we could still define the co-efficient of inductance and use the foregoing formulas just the same.

Those of us who know at what personal sacrifice and with what persistence Dr. Hering's experiments have been performed realize the debt of gratitude that we owe him. I say this, even though I do not believe that his experiments have in any way disproved the accepted laws. The experiments are purely qualitative, and in none of them, as far as I can see, the coefficient of self-inductance is smaller at the end of the motion than it is at the beginning. The derivative $d\, L / d\, s$ is positive, as it should be according to Kelvin's law. As to whether or not the actual mechanical force observed checks with the theoretical formula, the burden of the proof is entirely with Dr. Hering, or with someone who wishes to defend his views. The experiments in the present inaccurate form can hardly be used as a basis for a scientific discussion on such a fundamental law of nature.

John H. Morecroft: Dr. Hering's paper is rather difficult to discuss, as he makes so many ambiguous and general criticisms of our present laws, trying to show their inadequacy, but never apparently doing so, when one analyzes his methods. Such ideas as conveyed by the expressions "reactions of these forces on each other, or on a foreign force" and "abutments or anchorage of the forces in a field" certainly do not tend to clarify his arguments.

When one conceives of the electric current as moving electrons, as he is evidently beginning to do, it seems rather inappropriate to speak of the energy of the magnetic field as potential energy, as he does; this energy is due entirely to the motion of the electrons and so would naturally be classified as kinetic energy, while the energy of the electric fields of the electrons, present when the electrons are stationary, is better called potential energy.

The whole paper is so full of ambiguities and misleading statements that a complete discussion is out of the question, but an analysis of a few points Dr. Hering brings up is attempted in the following notes.

In discussing Fig. 1, in his paper he apparently thinks that the idea of current flowing in such a circuit is a new one; it seems well to point out therefore, that every time he telephones he is probably sending his voice current through just such a circuit, and that the telephone engineers use circuits of this make-up probably more than any other kind. The circuit of his Fig. 1 is closed through a condenser, the two plates of which consist principally of the two spheres A and B; the ordinary telephone circuit is closed in just the same manner, but there the condensers have a somewhat larger capacity than is the case in Fig. 1. In spite of this statement to the contrary, it is necessary to consider every circuit closed, if we wish to calculate how much current

will flow in it; what seems to constitute an "open circuit" in his Fig. 1 is rather a capacitive reactance between plates A and B, a reactance so high for ordinary frequencies that negligible current can flow and so it is classed by engineers dealing with ordinary power circuits, an open circuit. But there is no real distinction between an open circuit and a closed circuit, from the theoretical viewpoint; current will flow in any circuit in which there is electromotive force acting, especially if this is an alternating e. m. f.; the amount of current may be so small that its effects are negligible and the circuit is therefore called open. Actually the same law of current flow holds good for all circuits.

In such a circuit as that of his Fig. 1, this current would be so small in the ordinary test as not to be measureable and so the circuit is said to be open; if however a frequency of one hundred million cycles is used the capacity reactance of the condenser A-B is sufficiently low to permit the passage of measurable current and so the circuit would not be called open; the writer sees no reason at all therefore for any argument about this circuit; it follows the ordinary laws of circuits, as do all the rest of his circuits, one or two of which will now be discussed.

To clarify somewhat (even though only a little) some of the material presented in the paper, and to show how the author of the paper thinks and reasons, I will recall an argument he presented about fifteen years ago; I hope he will bear with me for doing so as the experiment he then described contains what seems to the writer a fallacy, which fallacy is present in some of the experiments contained in the present paper.

Can a circuit, being linked with some magnetic flux, be unlinked from this flux without having a voltage induced in it? That was the question Dr. Hering put to himself, and his answer

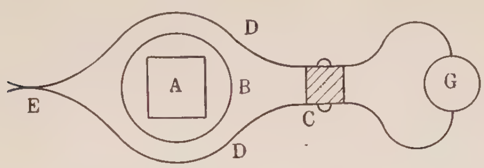

FIG. 1

was—Yes, arrived at as a result of the experiment now to be described.

His experiment was arranged about as shown in Fig. 1. An electric circuit consisting of the galvanometer G, two flat brass springs D, D, fastened to a wooden block C, and in contact at E, is linked with all of the flux through a bar magnet, shown in section at A. Around the bar magnet is fitted a smooth brass ring B.

By pulling block C (towards the right in Fig. 1) the springs D-D come in contact with ring B, further motion in the same direction opens the contact at E, and still further motion carries them around the ring, until they finally slide over the ring and again come in contact on the right side of the ring. This sequence of events is suggested in Fig. 2. In Fig. 1 the circuit evidently is linked with the magnet's flux, and in condition c of Fig. 2 it evidently does not, and hence, as the galvanometer has shown no deflection during the progress of this ingenious experiment, the author would have us conclude that a circuit can be unlinked from magnetic flux without having an e. m. f. induced in it. The results of this experiment, however, constitute no reason at all for the conclusion; our old ideas about changing interlinkages generating e. m. f's. are just as trustworthy after the experiment as before.

It will be seen that in position a Fig. 2 there is no longer *a* circuit involved in the argument, but there are *two* circuits, one of which (springs and left hand side of ring) still links with the flux and another (springs and right side of ring) which does not link with the flux. So, the experimenter has replaced *a* circuit by *two* circuits, *one of which does not link with the flux at all.*

I suggested at the time that the audience would understand the experiment better if it were performed as suggested in Fig. 3, the sequence of events being exactly the same as it was before, but the various steps being somewhat more evident. A circuit shown by the full lines of Fig. 3 links with the flux of magnet A; the wire of which the circuit is comprised being twisted together at a to complete the circuit. This is the same circuit as the experimenter started with in Fig. 1. Now a wire is connected from b to c, the wires are untwisted and separated at a, the magnet is moved through the opening thus created, the wires are again twisted together at a, the wire from b to c is now removed, and lo, the circuit has been unlinked and the galvanometer has not budged! Has the circuit been unlinked without generating an e. m. f., as indicated by the quiescent galvanometer?

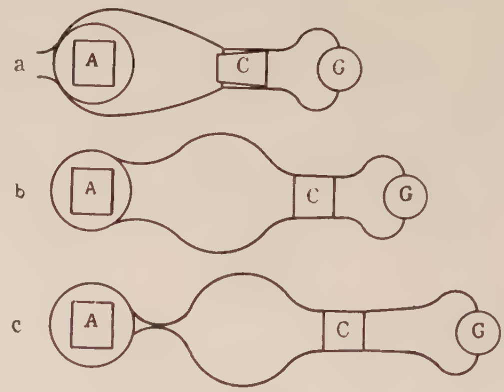

FIG. 2

Certainly not—the circuit has been opened at a, the magnet has been carried through the opening, and then the gap in the circuit has been repaired. The fallacy of such an experiment is evident to every one yet the author wished the teachers of physics to revise the theory they had been professing, on the basis of it.

This fallacy occurs repeatedly in the paper under discussion. When trying to show that a circuit does not have to move so as to include more flux in the circuit involved (a principle we still teach) he cites the case of the motor—"In the most usual case of the motor the flux does not increase but remains constant, hence the law fails even in the most usual case . . ." Here the brushes sliding on the commutator continually change one cir-

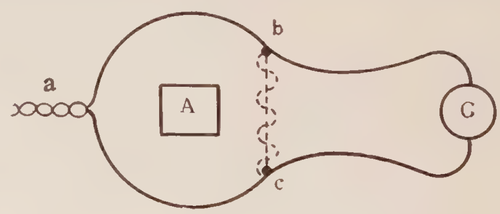

FIG. 3

cuit for another just *because the law does hold good;* if the circuit involved were not continually changed for another the motor would not turn. Let Dr. Hering solder two wires on opposite sides of the commutator of a bipolar motor and try how far the armature will turn. He will find that in this case *a* circuit (ensured in this case by soldering the wires in place) the armature will turn just as long as further movement will make the total interlinkages of the system a maximum, and *there it will stop,* just because the law does hold good in this case.

Although it would undoubtedly prove a fascinating pastime it is obviously impossible for one man to carry out all the experiments suggested by the author, unless he devotes considerable time to the task; one easy experiment he suggests however,

which seems a typical one, so I took the time to carry it out more carefully than he had apparently done. The experiment is the one indicated in Fig. 4; the question is—which way will the wire W move? The results of the test are supposed to disprove the theory we teach, namely that the wire will so move as to make the included flux increase.

The older law (which presumably is at fault because predicting the wrong answer in this case) says that the circuit should so re-arrange itself as to make the flux interlinkages increase—yet according to the author the wire W moved in such a way as to decrease the enclosure, and so presumably disproves the law. (It is to be noted that here also the circuit is not a definite one, the motion of the wire making the length of the circuit greater by the amount of mercury trough introduced into the circuit by its motion). It is a fact that if one tries (and understands the old fashioned law) he can so fashion the circuit that the wire W *moves in*, as stated by the author, but that same knowledge will give him the idea as to how he can fashion the circuit so that it will *move out*. The phenomenon needs no new laws for its explanation although such is apparently believed by the author. The explanation of the result of the experiment is this—*the circuit will so rearrange itself so as to include the maximum flux*, the current presumably being held constant. But *this is the older law*.

I made up several circuits with mercury troughs and movable wires and tried the motions of the wires under various conditions. After eliminating the effects of the earth's field (this can be done

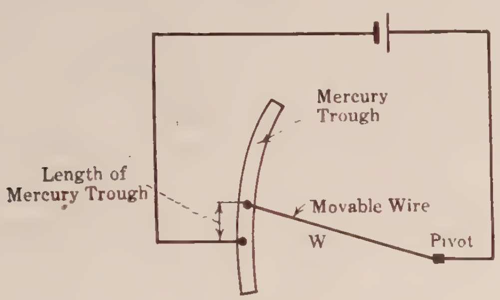

Fig. 4

by using very large currents in the circuit) I found certain combinations which would make the wire W move out, and others which would make it move in. In Fig. 4, for example, if the wire W is put a sufficient distance inside the rectangle to start with, it will move inward and find a position of stable equilibrium; if the wire is pushed farther into the rectangle the forces exerted on it push it outward; there is a definite position of equilibrium for a definite circuit. If the back wire of the circuit (on the side of the rectangle opposite to W) is too close to W, that is, the rectangle is a narrow one, the wire W will always move outwards. All of these effects can be calculated by the older laws but as it seems that the author is more amenable to experiment than to the calculus, I made some quantitative determinations on some of the circuits. As the interlinkages of a circuit are measurable by determining the self induction of the circuit I used this method for finding out if the circuit did always so move as to increase the inter-linkages. One turn of wire, a few inches in dimensions, has a rather low value of self induction so it is necessary to use fairly high-frequency current to make the determination. I used a frequency of four million cycles a second.

A heavy current was sent through a circuit essentially like that given in Fig. 4, letting the movable wire come to its position of stable equilibrium. By a resonance method I then determined the self induction of the circuit for various positions of the movable wire, obtaining results in a typical case as recorded herewith.

Length of mercury part of circuit	Self induction in microhenries
0 inches	3.36
2 "	3.36
4 "	3.43
6 "	3.47
8 "	3.50
10 "	3.46
12 "	3.43
14 "	3.41

The position of stable equilibrium for the movable wire was when the length of mercury trough was eight inches, thus showing indisputably that this experiment, which the author of the paper thought disproved the older laws, actually vindicates them. He evidently jumped to the conclusion that if the enclosed area became smaller the self-induction must also necessarily be smaller. This is only the case if the length of the wire comprising the circuit is constant in length; here the circuit becomes actually longer as the movement of the wire includes more of the mercury trough in the circuit; *the circuit is thus indefinite, sufficiently so that this very thing led the originator of the experiment to jump to the wrong conclusion.*

In a similar way the motion of the conductors in all of the combinations shown in the authors Figs. 3 to 11 so take place that the flux inter-linkages increase. For example, in his Fig. 6 the more that trough M (of large cross-section, and hence low L per unit length) can be replaced by trough m (of smaller section, hence greater L per unit length) the higher will be the self induction of the circuit.

In such an experiment as that shown in Fig. 5 of the author's paper we have to bear in mind that we do not have *a* circuit to deal with, length being continually added to the circuit conductor as the bridge moves. From what has been said and shown above it seems evident to the writer that we may still use the old laws in our teaching, without running the risk of teaching any fallacies. We must, of course, try to instill into the student's mind that he must think accurately, not confusing one circuit with another—he must not be willing to apply a law to a case which involves premises which the law does not. It seems to the writer that the older laws, about which doubt was supposed to be cast by these experiments, are rather substantiated by them.

John Mills: I have had no opportunity unfortunately to try out any of these experiments. I approach the problem very much from the standpoint of the remarks of past President Mailloux and I wish to use the occasion to arouse a further interest in the mechanisms which underlie the phenomena Mr. Hering describes.

I think Mr. Hering's interesting paper should be approached in the spirit of one who recognizes that the past twenty-six years, since J. J. Thompson identified the electron, have been revolutionary and scientific concerts. He calls attention to a much needed reconsideration of our formal expression and exposition of electro-magnetic phenomena. Today, we have electronic mechanisms which Maxwell and his immediate successors did not have. Today the ether is the most debatable assumption and energy and an electrical matter are the two entities with which the electronic physicist deals most consciously. With Mr. Hering's fundamental appeal for recognition in our expositions of underlying mechanisms I am most heartily in accord. I have tried some missionary work along that line myself but with relatively small success.

Without any regard to the criticism which can be directed towards the experiments which Mr. Hering has presented let us consider his Fig. 4, and look at it without reference to the inductance. Imagine billions of electrons rushing along from the negative terminal of the battery, along the connecting wire and

plunging into the liquid of the trough. Then remember that each of these electrons is about 1/1845 of the mass of a hydrogen atom. Remember that for the currents used there would be about a thousand billion billion of these electrons taking that plunge each second. Now I simply raise the question: Is it inconceivable that, as they do plunge, they should kick back on the slider? I do not believe it is inconceivable,—and I cannot see—and here is where I differ and am unpopular—I cannot see that flux and other Maxwellian concepts enter into the problem at all.

Whether or not, however, these electrons, in their obedience to Newton's third law of equal action and reaction will result in a perceptible motion of any given slider is a question that the electronic physicists can answer for us, either from data at hand or by simple but refined researches.

I admit our knowledge is incomplete, but it seems to me our knowledge has to be expressed in terms of the electron of which we have heard for twenty-six years. We may apply the same ideas to other figures of the paper by Mr. Hering and reach similar conclusions. In each case, however, the problem is one of electrons and is not a problem of flux nor a problem of "stretch effect." If there is a stretch effect it must be explainable on an electronic basis.

Two of the experiments, namely those of Figs. 3 and 6 are conceivable upon the electronic basis mentioned above but require a recognition of the fact that because the shape and sizes of the vessels, into which the moving wire dips, are dissimilar there will be possible dissimilar conditions of turbulence due to thermal effects. One could have wished that Mr. Hering had approached this investigation more directly from the view point of electronics and obtained quantitative results.

H. G. Brinton: In connection with the subject of fundamentals, I would like to say a few words about fundamental electric fields and the electron theory.

The electron theory is not completely perfected. There are some phenomena which it has not yet explained, although it is accepted as our most fundamental theory and deals with the constitution of matter as well as electric and magnetic phenomena. The phenomena of gravitation and of the propogation of electromagnetic waves through space are two of the most interesting cases of unexplained phenomena. There is also need for more clear and fundamental explanations of other phenomena, as pointed out by Dr. Hering. These unsolved problems make a consideration of the fundamental theory still more fascinating. I have made a study of this subject as a matter of personal interest and have worked out a development of the electron theory which affords a basis for the explanation of gravitational as well as electromagnetic phenomena.

The point of view of this discussion is based on the idea or fact that we have no conception of the ultimate essence of electrons, protons, and fields of force. We only know how they act. The human mind has not been capable of going further than that. What is spoken of as "knowing the ultimate nature of matter" can only consist, under present conditions at least, of a detailed knowledge of the nature of the behavior of the smallest units. We consider matter as made up of a large number of fundamental units. From this point of view, an explanation of complex phenomena involving fundamental units, will be a statement of the actions taking place, in terms of the actions of fundamental units and in accordance with fundamental laws. The things we now consider most fundamental cannot now be explained in terms of anything more fundamental, but our ideas in regard to what is most fundamental are subject to change. Our fundamental ideas must be judged by their consistency with each other and by their utility as a basis for explanation.

The fundamental units of matter should involve electrons and protons in some way. Since we regard electrons and protons as primarily centers or terminals of fields of force, it seems logical that the fundamental units should involve electric fields of force. Let us therefore take, for a fundamental unit, the field of force extending from a single proton to a single electron. We will retain the idea that electrons and protons maintain their identity and assume that the fundamental unit fields of force maintain their identity under all conditions. There is such a field of force extending from each proton to every electron. What we usually have called an "electric field" must now be called a "resultant electric field" to distinguish it from the fundamental unit electric fields.

We have to consider next the inter-action of these fundamental fields. The action of a single field needs no description here. Let us consider the case of two positive particles with fields directed outward from each particle, or the case of two negative particles with fields directed inward to each particle. In these cases the adjacent fields are in the same direction or have components in the same directions, and we know that there is a resultant force tending to move the two particles apart. We may, therefore, say that two adjacent fundamental fields in the same direction tend to move apart. This is the same action that takes place within a single field. If one field is superimposed on another field having components in the same direction, but of varying intensity, the first field tends to move away from the stronger part of the second field as a result of the combined actions of adjacent parts of the fields. This resultant action is what determines the direction of the resultant force tending to move two positive particles or two negative particles away from each other.

In the case of two particles, one of which is positive and one negative, we have fields directed outward from the positive particle and fields directed inward to the negative particle. In this case the two adjacent fields have components in opposite directions and we know that the two particles tend to move together. To be consistent, we must say that two fields having components in opposite directions tend to move together. This is the direct opposite of the action between two adjacent fields in the same direction. There is, however, another action to consider in the case of a positive and a negative particle. In addition to the fields referred to above extending to and from the surroundings, there are fields extending from the positive particle to the negative particle. These fields, which are an inherent part of this particular combination, make the resultant attractive force between a positive particle and a negative particle slightly greater than it would otherwise be.

Now consider the case of two neutral particles. In this case the field directed outward from each particle is exactly equal and opposite to the field directed inward to that particle. The field directed outward from one particle tends to move away from the outwardly directed field, but toward the inwardly directed field of the other particle. The resultant of such actions in this case is zero. There is, however, a resultant force of attraction, which is due to the fields extending from the protons of each body to the electrons of the other body. This particular resultant force is called "the force of gravitation." We know that a gravitational field of force is not affected by the presence of any other gravitational or electric field. This is due to the fact that a gravitational field is composed of two equal and oppositely directed fields and the resultant action upon other electric fields is zero.

From this point of view, we may easily show why we have electromagnetic waves but do not have gravitational waves. A gravitational field, being composed of two equal and oppositely directed electric fields, cannot set up any magnetic field by its motion in one direction. On the other hand, the movement of a magnetic field does result in actions upon gravitational fields, moving one electric field in one direction and the oppositely directed field in the opposite direction. Thus, when an electromagnetic wave is moving in space, the resultant electric fields are due to the separation of the component electric fields which

form the gravitational field. When the electric fields separate, energy is transferred to the electric fields. When the electric fields recombine, this energy is transferred from the fields at that point. Thus, energy is transferred from point to point as the wave moves through space. The magnetic field must have been set up in the first place by the movement of a resultant electric field. For example, the movement of electrons sets up magnetic fields and results in electro-magnetic waves.

The fact that electrons play a more active part than protons play in electrical phenomena may be explained as follows: The number of electrons in this universe is much greater than the number of protons. There is a fundamental field of force extending from each proton to every electron. The number of fundamental fields of force terminating on a single proton is, therefore, much greater than the number terminating on a single electron. That is, the total field centering on a proton is much greater or more intense than the field centering on an electron. For this reason an electron can be moved by electromagnetic actions much more easily than a proton.

Gravitational actions are comparatively simple and the explanation is therefore correspondingly simple. In the case of the actions and interactions of electric and magnetic fields, the phenomena are very complex in most cases and the explanation is correspondingly difficult and complicated. We will consider at present two of the more simple cases.

We know that the effect of inductance is to oppose the increase or decrease of a current in a conductor. Consider the case of a current flow in a wire. When such a current starts to decrease, the magnetic field around the wire contracts and the movement of the magnetic field results in a pressure upon the inwardly directed field, causing such fields and associated electrons to move in one direction along the wire. We need not consider, for present purposes, the action upon protons, because it is principally the electrons that move as stated above.

In the case of a loop of wire rotating in a uniform magnetic field about an axis at right angles to the field, we know that there is flow of current and an induced voltage in the loop. In this case we have to consider the action of the magnetic field upon the fundamental fields between the two sides of the loop which are parallel to the axis of rotation. There are two equal and oppositely directed sets of fundamental fields to consider. These fields extend from the protons of each side of the loop to the electrons at the other side. As a result of the motion of these fields relative to the magnetic field, the electrons (referring to those that move) in one side of the loop are moved in one direction and the electrons in the other side of the loop are moved in the opposite direction. There is thus a tendency for the circulation or flow of electrons around the loop. The direction of motion may be found by the well-known three finger rule for induced e. m. f. taking the direction of movement of electrons as opposite to the direction of the e. m. f.

The electron theory is our fundamental theory and should be used for the explanation of electromagnetic phenomena. The electron theory has, however, been in need of some development and improvement before it could form a satisfactory basis for explanation.

R. E. Doherty: I wish to discuss in particular the statements made in the appendix of this paper, since this is the only place where either a numerical value, or an equation appears. I submit that although a number of our so-called physical laws may possibly be wrong, including the one attacked by the author, it is not a sound policy to conclude that the law is wrong just because the force on some part of a complicated electromagnetic system does not happen to be in the direction one would expect, from a knowledge of the law and a visual inspection of the apparatus. From a tilted railway car, a stream may appear to run up hill, but in fact, of course, it does not. And just as in the railway car a proper set of measurements could show whether the law of gravity had ceased to operate, so in the present case, quantitative tests could show whether the law is actually or only apparently wrong. This may well be left to physicists.

But the ideas developed in the Appendix can be discussed in a decisive way. Starting with a neutral copper ring of zero resistance, it would be very interesting to learn the details of the author's process of establishing a magnetic field linked with this ring, and a current in it which will flow indefinitely. The current will flow indefinitely, of course, if a magnetic field linking the ring is established; but establishing such magnetic linkage in the given neutral ring is the first point which I cannot fathom. If there is a single law which can be used as a starting point, it is that in a closed ring

$$\frac{d}{d\,t}\,(L\,i) + r\,i = 0$$

If r is zero, then

$$\frac{d}{d\,t}\,(L\,i) = 0$$

That is, constant magnetic linkages. Hence, if the linkages are initially zero, they must remain zero.

Or for two closed rings,

$$\frac{d}{d\,t}\,(L_1\,i_1) + r_1\,i_1 + \frac{d}{d\,t}\,(M\,i_2) = 0$$

and

$$\frac{d}{d\,t}\,(L_2\,i_2) + r_2\,i_2 + \frac{d}{d\,t}\,(M\,i_1) = 0$$

If $r_1 = r_2 = 0$, as assumed, then

$$\frac{d}{d\,t}\,(L_1\,i_1 + M\,i_2) = 0$$

and

$$\frac{d}{d\,t}\,(L_2\,i_2 + M\,i_1) = 0$$

But the first of these gives the magnetic linkages of the first ring, and the second, the linkages of the second ring. That is, the linkages must be constant in each ring. And if they are zero initially then they must remain zero, whatever else happens, so long as the rings are closed and have zero resistance.

Therefore, the deductions in the appendix are wrong. The magnetic linkages cannot decrease or increase in a closed ring without resistance.

Inasmuch as the equations used by the author assume the validity of the above equations, the conclusion would seem to be clean cut.

It may be of interest to further point out that the author's proposed law is merely a specialized re-statement of the commonly applied principle that the electromagnetic force *acting on* any part of a circuit is

$$f = 1/2\,i^2\,\frac{d\,L}{d\,x}$$

where, $\frac{d\,L}{d\,x}$ = the rate against distance, not time, at which the total inductance of the circuit would change if motion of that part of the circuit occurred in the direction of the force.

i = instantaneous value of current.

The author's proposed law is: "in an electromagnetic system in which the current is being maintained by a source, any and only such mechanical motions of the conductor will tend to take place as will generate a counter e. m. f. somewhere in the circuit."

The counter e. m. f. which the author defines here is,

$$e = i\,\frac{d\,L}{d\,t}$$

Of course if there are circuits in inductive relation to the one in question, the force is given by

$$f = 1/2\, i_1^2 \frac{d\,L_1}{d\,x} + \sum i_1\, i_s \frac{d\,M_{1s}}{d\,x}$$

and the counter e. m. f. referred to, is given by

$$e = i_1 \frac{d\,L_1}{d\,t} + \sum i_s \frac{d\,M_{1s}}{d\,t}$$

Furthermore, using the above familiar expression for force, it is easily demonstrated that it is not necessary to assume, as the author does, the special case of constant current. The expression gives the force existing for the particular current, whether the latter is rapidly varying or constant.

In other words, the proposed law is not new, and hardly merits the name of a *law*, for it is merely a re-statement, with an unnecessary limiting condition, of a long established corollary of the Law of Conservation of Energy, from which the above mathematical expression at once follows.

Thus to summarize, all of us will probably agree that, for the profession, it is a wholesome and commendable thing to review and question, as the author has done, the validity of our fundamentals, and to demand an explanation of certain observations which appear to him to be in contradiction to the so-called *laws.* However, I do not agree that he has demonstrated the invalidity of the law of electromagnetic induction in the particular application of determining forces. On the other hand, the fundamental assumptions involved in the equations given in the Appendix, contradict the conclusion there arrived at. Also, the proposed new law is merely an incomplete re-statement of a well-known corollary of the Law of Conservation of Energy.

E. H. Kennard: Dr. Hering's paper arouses in me very mingled feelings. With his criticisms of the textbooks I feel compelled to sympathize to a considerable degree. The writers of textbooks ought, I think, to remember that their books are sure to be employed more or less as reference books and the text ought to be so written that it cannot be misunderstood by any attentive and thoughtful reader. Every exception or restriction upon the scope of a law ought to be mentioned, at least in a footnote. And then, besides imperfections of statement, many books contain a distressing number of genuine errors. But to err is human and we shall never see perfect books.

Let us take up Dr. Hering's chief points in order.

1. *Do circuits tend always to increase their flux?* I think that they do; Dr. Hering's own experiments confirm this law. Of course, in calculating the change in flux one must imagine the current to be kept constant. This assumption will be found to underlie all deductions of the law, although I am afraid that textbook writers do not sufficiently emphasize the point.

In Dr. Hering's Fig. 5, a careful study of the flux shows that the motion increases the flux no matter on which side the battery is placed, for when we flop the circuit over to the other side of the mercury troughs we reverse the direction in which a line of flux must be called positive as it passes through the plane of the paper, and this reversal compensates for the change in the location of the area enclosed by the circuit.

What this experiment really shows is that a circuit does not always *enlarge* under the action of its own flux—and I must admit that some textbooks make wrong statements about this. I think that any plane circuit so shaped that it bends always toward the same side as we go round it, will always tend to enlarge under its own electromagnetic forces, whereas this may not hold if the circuit contains a part shaped like an *S* or a *Z*.

The law holds also for Dr. Hering's imaginary experiment in which two rings of no resistance have currents induced in them and are then brought toward each other; for the currents in the rings do not remain constant. We can write for each ring $L\,d\,i/d\,t = -\,d\,\phi/d\,t$ where ϕ is the flux through the ring due to the current in the other one; this equation gives by integration $L\,i + \phi = \text{const.}$, which shows that the flux through each ring remains fixed forever. Hence as the rings approach and the mutual flux increases, the flux of self-induction, $L\,i$, must decrease, and so must the current, i. Thus the change in flux produced by the motion, which determines the mechanical force, is exactly compensated for by another change caused by the change in the current, and this is why the flux through each ring remains constant.

2. *A General Law of Motion.* Dr. Hering emphasizes two principles, (1) that potential energy tends to become kinetic, and (2) that no motion can be produced by electric currents, at least in the absence of iron, without the generation somewhere of an e. m. f. These two principles are, of course, well known both to physicists and to engineers, although the proposal to make them the foundation of the theory of electromagnetic forces is, perhaps, new. The merits of this proposal are a matter of opinion; for myself, I cannot feel that the proposal is a good one, but the subject is too large for discussion here.

3. *A longitudinal force* is not shown to exist by Dr. Hering's experiments, which are entirely explained by the accepted laws, as I shall show presently.

4. *Sliding Contacts are a Nuisance.* So they are. To the mathematical theorist every discontinuity or abrupt change in conditions is a nuisance and requires a special explanation. The usual practise among physicists (except, perhaps, among the French) seems to be to state the general laws of physics as if such discontinuities did not exist, and then to replace the discontinuous cases by an equivalent continuous one.

The law of induction I like to state in three steps as follows:

(a) *Definition.* A circuit means a closed filament of matter.

(b) The *E. M. F. induced* in any circuit (measured in electromagnetic units) equals the time rate of decrease of the flux that is linked with the circuit.

(c) At a *sliding contact* one may imagine a thin layer of conducting liquid to be inserted between the sliding surfaces, so that there will be a continuous gradation of motion through this layer and permanent elementary circuits can be drawn through the layer.

There are other good ways of treating sliding contacts, of course; the essential thing is to have some sound method of doing it that one understands. My own opinion is that such a transition layer really exists, in the form of interlocking electron atmospheres if not in the form of a layer of pulverized metal.

This law refers only to closed circuits but has, I think, no exceptions. Open circuits are a different proposition.

Of course a statement can be given in terms of the cutting of the magnetic lines by the conductor which is mathematically equivalent to what I have just stated. But I do not think that physicists will ever wish to substitute this statement of the law in terms of line-cutting for their own formulation, because in many cases, such as a transformer, one has to introduce a motion of the lines themselves that is imaginary and arbitrary, or at least not susceptible of observation, and then in order to make any calculations one passes right back from the line-cutting conception to the variation of flux that is referred to in the physicists' statement of the law.

If it were possible to state a simple general law for the electromotive force induced in each part of the circuit, this sliding-contact difficulty would disappear. For the dynamo type of induction, where the conductor moves and cuts the flux, such a law can be given, and is, in fact, well known. But in the transformer type of induction, where the flux itself moves or changes, the exact location of the induced e. m. f. can be found only by solving the Maxwell equations for the electromagnetic field, and such a solution has to be worked out anew for each special case. Under these circumstances the simplest plan would seem to be the one actually adopted, to state the value of the e. m. f. in the whole circuit in terms of the total flux.

5. *The experiments* described by Dr. Hering are interesting

but are quite inconclusive. Every one of his results is easy to explain in terms of the familiar "motor rule" for the transverse force on a conductor, although in the absence of quantitative measurements one cannot always be sure which of two or more factors is actually effective.

Thus in Figs. 3 to 7 inclusive the magnetic field produced by the *liquid* part of the circuit has in all cases the right direction to account for the motion, which is due to the transverse forces thereby exerted upon the moving piece. In Figs. 3 and 6, this force must be greater upon the vertical part that dips into the narrow trough than upon the wire dipping into the broad one because of the difference in concentration of the current. I feel pretty sure that this explanation is correct but cannot be quite certain of it in the absence of exact data which would make possible a numerical check.

Figs. 16-17 are unusual only in the presence of a sliding contact, which has to be treated here in the same way as one treats it in applying the law of induction if one wishes to deduce the motion from the law that a circuit seeks to increase its flux. Or, the usual "motor rule" for the force on a conductor is also easy to apply and gives the correct results.

In Figs. 9 and 12 the argument turns upon an application of Newton's Third Law. But, owing to experimental difficulties, the validity of this law has never been established for current elements. As a matter of fact, if the modern theory of the electron is correct, Newton's Third Law does not hold, in general, for the mutual actions of two moving electrons (although by modifying its meaning the law can be made to hold for the electrons and the ether taken together), and it follows that action and reaction are not usually equal for two current elements (or for a current element and a magnet), although the law *is* true for an element and a closed circuit. Thus, before Dr. Hering can infer from the existence of a force upon V in Fig. 9 that there will be a longitudinal force upon H, he must prove by experiment that Newton's Third Law holds for parts of circuits. Otherwise he is himself guilty of that blind dogmatic faith in old laws of which he accuses the physicists.

The observed motion of H in Fig. 9 arises, I think, from forces at the ends, where the currents are unequal.

As to the motion in Fig. 18, I shall associate myself with those who, according to the author, ascribe it to the pinch effect. The magnetic field at the mouth of the tube leading to R pushes the mercury toward the axis of the other tube and so causes the flow. That is, the mercury just at the end of the side-tube is itself squeezed toward the axis of the main tube and so is prevented from escaping into R, as Dr. Hering thinks it should. I have no desire to be presumptuous, but in reading Dr. Hering's discussion of such cases I am sometimes led to wonder whether he has not underestimated the training in habits of exact and consistent thought which is necessary in order to reason correctly about hydrodynamical phenomena.

The more complicated motions in Figs. 8, 10, 11, I should also ascribe to the same action as that which produces the pinch effect or to analogous actions upon solid conductors.

Thus none of these experiments points unmistakably to the existence of a longitudinal force.

Carl Hering: The present discussion, the far more extended though unfortunately unrecorded personal discussions for some years, and the republication of a translation of the entire paper in a French journal, in many of which there are a number of quite favorable comments, are far more encouraging than was to be expected from the strenuous efforts which were made against the acceptance, publication, and reading of this paper. It is no credit to our profession that modest attempts, based on experimental researches and discussions extending over years, to bring some of the acknowledged antiquated factors in our branch of science up-to-date in order to correspond better with modern developments and to open up new fields, if any, which orthodox teachings had closed to us,—should be discouraged by being met with such strenuous efforts chiefly by book writers and teachers, to suppress their publication, even including public attempts at personal ridicule, instead of being welcomed and encouraged by co-operation and constructive criticism. A true scientist is characterized as one who is grateful instead of angry to have pointed out to him any shortcomings, imperfections, inadequacies, omissions, possible errors, etc., in the orthodox views, and suggested improvements open for criticisms.

Apart from attacks on things I did not say, the discussion did not prove a single error in any important point, and it is safe to assume that if the paper had contained any actual error it would surely have been brought out and used as ammunition by the opponents to the suggested reforms. Hence the statements in the paper must be allowed to stand on whatever merits they may have. Differences were entirely on matters of opinion and not on matters of fact; attacks on things I did not say are not proper discussions. Many of the unorthodox statements were not attacked at all, which may be significant.

The proposed general law of electromagnetic motions was not only not attacked but was upheld and proved by others; engineers and students may, therefore, now feel safe to depend on it; I have for years found it far more useful, clear and direct in practise than the older laws which it is intended to replace. Students will be pleased that they need no longer burden their brains with complicated and confusing definitions of that subterfuge "sliding contacts."

The strenuously opposed and long neglected longitudinal force was strongly upheld by some able discussers and disproved by none; the worst that opponents could say about it was to the effect that they could get along without it. The verdict of the opponents is to the effect that the old laws are good enough for them; their students and followers may fall into the same pitfalls that I did years ago while I still had gospel faith in our old laws, and they will not be able to use some useful available new tools, the lack of which may handicap them in competition with those who are not hidebound to traditions, and in the developments in new, formerly forbidden fields which now appear to be open to us.

Practically the only attack of importance by several discussers, concerns those old laws which are to the effect that there must always be an increase of flux and of self inductance when a system does mechanical work. These critics claim that I have denied the corrections of these laws. As there is no such denial in the paper, these critics in this case as also in several other cases in which I did not say what they are attacking, have merely set up a straw man in order to have something to knock down. Discussers ought to read a paper carefully before they attack it.

I had even admitted that in many cases these laws apply correctly, although in some a highly involved, very artificial, confusing definition of sliding contacts (like the very old one used in Prof. Morecroft's discussion), or other limitations, must be included to make them apply. Many misfits can be made to fit, and our ignorance be made to appear to be wisdom (at least to the unsuspecting student), by resorting to an involved definition of sliding contacts, especially when the student cannot understand the definition.

What I did claim, and do so still, now even stronger than before, as my opponents could not deny it, is that these laws are special case laws, and not the most fundamental or universal ones. A universal law is one which can have no exceptions, but these older laws have, as was clearly shown. To exclude these exceptions (and probably others also) it is absolutely necessary to read some limitations, restrictions or qualifications into the law, so that it will fit and not mislead; these, of course, make it a special case law, as it then admittedly does not apply outside of these limitations. This, of course, leaves us *without any law* for all cases outside of those limitations, which is the best proof that it is not a universal law. There may perhaps be very useful cases which are outside of these limitations. One of

these proposed restrictions is "provided the m. m. f. does not change;" another is "provided there are no structural changes," yet in every motor there are continual structural changes of the circuit at the commutator. Moreover it is surely no crime to change the m. m. f. or make structural changes, if something useful may be gained thereby, and for these cases we had no laws. One of the chief purposes of this paper is to help those who desire to work in new and formerly forbidden fields.

In my opinion taking refuge behind a "sliding contact" to make misfits fit, is unscientific and a tacit admission that there is something wrong somewhere, either in the subject or in the teacher or book writer, when that old fashioned subterfuge becomes necessary. Sliding contacts used as a subterfuge in explanations can now be (as I have shown), and should now be, ruled out as obsolete, if they are not, the students have my sympathies. Moreover these laws seem to be taught so as to leave the impression in the mind of the student that such increase of flux and self induction were in some mysterious way the *cause* of the motion (which they are not, though in many cases they are incidental to it, due to the connected outside source of energy, as I showed), and that without such increase there could not possibly be any self produced motion; this is not true and ought not to be taught.

The self inductance (a purely geometric quantity) depends greatly on the number of turns, while the flux and flux energy (on which the forces depend) are quite independent of the number of turns being a function only of the ampere-turns; for the same ampere-turns and a given reluctance, hence for the same flux and flux energy, the self inductance may have very greatly different values when the number of turns is changed; to give the student the impresssion that the self inductance and the flux and flux energy always go hand in hand, is positively wrong. To define A in terms of B when B varies greatly with a factor that does not affect A, is *not* a proper definition. By combining the self inductance and the current as one quantity (representing flux and flux energy) useful laws and undoubtedly correct calculations may be made, as admitted in the paper, but the student should by all means be told (though apparently he is not) that this is limited to special or restricted cases, and is not universally true; this was shown in the paper.

The presence of iron moreover increases the self inductance and the flux very greatly, yet the flux in the iron may not always be free to produce motions; an iron pipe around a centrally located conductor would presumably not increase either the pinching or the stretching forces, notwithstanding the greater flux and self inductance. Hence formulas based on self inductance may sometimes give wrong results.

The chief other point in the paper which the opponents attacked, though ineffectively, is the one concerning the two rings at nearly 0 deg. absolute, though no one has shown the statements made in the paper to be incorrect; this case shows clearly that the flux and flux energy *diminish* when there is self produced motion. In this case the two rings were, and must of course be, considered together as forming one system; to treat one ring and its linkages by itself, as some have done, leads to nothing new and useful, and is improper as one ring does not constitute the whole system.

The real purpose of this example was apparently lost sight of or was not grasped by the opponents, namely to completely separate an electromagnetic system, containing stored energy, from any outside source of new energy, in order to be able to study this stored energy alone and by itself without any interference by new energy. This can easily be done with electrostatic systems, but it is believed that this is the first time an experiment was devised in which this could be done with an electromagnetic system. Our old book laws (like the very old Kelvin law) were always based on the *united action* of *two* things, the stored energy and a source of new energy inseparably connected; never before (I believe) could the stored energy be experimentally studied separately, and this is very necessary in order to get at the real fundamentals. A single equation with two unknowns cannot give the values of each by itself, it is incomplete information; so is an experiment or law involving the inseparable joint action of two factors, as in the old Kelvin law.

The above answers the discussion in general. The constructive discussion of Dr. Mailloux is a contribution of value and importance. His remarks about infinity are especially important, as they explain the absurdities, inconsistencies and even serious fallacies arrived at by even able expert mathematical physicists when they have recklessly jumped into that dangerous abyss, infinity; and still worse, have then tried to force their unacceptable conclusions on to the more cautions thinker or on to the trusting, unsuspecting student, thereby tending to muddle his brain and to check progress. The bringing out of his discussion on infinity has been one of the useful fruits of the paper.

His references to the able work of some of the older French physicists who sometimes disagreed with Maxwell, will no doubt surprise the orthodox, hidebound, Maxwellians who seem to consider it a crime to even question anything which that admittedly brilliant mathematical physicist said 50 years ago, as though progress in science was not possible. The writer, who has discussed these subjects for years with many, has found that there are many progressive physicists who do not consider all the 50-year-old Maxwellian views to be incontestible today, and who admit that progress has since been made. Able physicists have admitted that the Maxwellian "complete circuit" restriction has long ago been abandoned as the most fundamental case and is now out of date and behind the times; it refers to a special case only (though the most usual one) and when so restricted is very useful. Today we must admit that an electron can start from rest at a point A, move to a point B and stop there, that is, it is no longer necessary to involve all the other electrons in the world or universe in this localized action. The old conception that the "complete circuit" is the most basic fundamental one has checked progress and is now antiquated: students should be told this.

Dr. Mailloux's statement that Mascart and Joubert recognized the stretching force, is interesting in view of the strong opposition from lesser lights. That Bjerknes thought all the actions in his experiments could be explained with a single force, is of interest as his experiments were made in liquids which we know act hydro-dynamically. Dr. Mailloux's criticism of the clause "action at a distance" seems to be due merely to different uses of the term; moreover it is used only incidentally in the paper.

Prof. Karapetoff lays great weight on the old Kelvin law. The pioneer dynamo and motor builders, who were no doubt brought up on that law, as I was, soon had to unlearn it in order to construct dynamo and motor installations having a greater efficiency than 50 per cent, which is the greatest that this law proclaims. Practical men must sometimes set aside old theories that mislead. His insistance on a "constant current" shows that this law does not apply to my two-ring example in which there is intentionally no source attached to the system. He evidently did not read the paper carefully as the paper *does* show several cases in which "the coefficient of self inductance is smaller at the end of the motion than it is at the beginning." To exclude these exceptions so-called "patches" (limitations) must be put on the old law to cover the dents made in it by these cases; the law then is admittedly no longer a universal law.

He condemns the paper because it does not also give quantitative results and for that reason calls the experiments "inaccurate," which seems improper criticism as the results in all cases were very decided and left no doubts. In every new investigation qualitative experiments are, and should always be, conducted before the quantitative ones, and the fact that they must be made first should not condemn them. To condemn a

paper because it does not contain what it was not intended to contain, is not fair criticism.

But in this criticism he (like others) ignores completely a most important and crucial *quantitative* result shown in connection with Fig. 6, namely that the longitudinal force so strongly opposed by the orthodox physicist, actually overpowers the standard perpendicular forces on which the orthodox physicist depends entirely for the support of his theories; this surely is decidedly a quantitative result, not only in amount but in sign also.

Prof. Morecroft admits he does not understand the paper; as many others have understood it, it seems that the fault is not mine. Yet he discusses at great length what he admits he has not understood! As he differs from many others in his views, his free and unqualified use of the term "fallacy" is not a serious matter; it expresses only his opinion. The difference between kinetic and potential energy is a relative one; the pressure of a confined heated gas often and properly considered as potential energy, is a bombardment of the molecules, hence kinetic, in a sense. Maxwell has also treated magnetic energy as potential. The kinetic energy in a spinning gyroscope may be considered as potential in some problems; it is a case of relativity again. There is nothing in the paper which warrants his saying that I thought "that the idea of a current flowing in such a circuit (Fig. 1) is a new one," in fact I said "it is known."

The conception in Fig. 1, is as old as the electron theory. In saying "it is necessary to consider every circuit closed" he is not in accord with many of his more progressive colleagues.

His long and very complicated description of my 15-year-old experiment, is a mere republication of an old argument published fifteen years ago, which I thought by this time was considered out of date and behind the times. It well illustrates the desperate efforts which many make to seek refuge in the "sliding contact" subterfuge. There are at least several other cases (*Jour. Frank. Inst.* Nov. 1921 Figs. 4 and 6) and probably many more, of which he does not appear to be informed, in which the linking and unlinking of flux with a *closed* circuit induces no e. m. f., and for each of these he would have to invent a new theory of the "sliding contact." The alternative to his long, complicated description is the simple statement that to induce an e. m. f. the flux must cut the material of the conductor and not merely the circuit. This I understand also agrees with the more modern electron theories. It can safely be left to the students and engineers which of the two explanations they prefer. If they are not taught the latter, they have my sympathies, as they may then fall into the same pitfalls that I did before I found this important difference between the circuit and the conductor, which I believe is now generally recognized by progressive men, as it is easily proved. It has now been known for about 15 years and no one has shown that it is not correct, although strenuous attempts have been made for years by theorists to disprove it, or failing in this, to suppress it, merely because it interferes slightly with their 50-year-old theories and their present teachings.

Prof. Morecroft says that it seems that I am "more amenable to experiment than to calculus." Yes, this is true when the calculations are based on man-made laws; in experiments nature talks to us.

His explanation of the constancy of the flux in a motor rests on the sliding contact subterfuge, hence involves a complicated description, which the student could be spared. Concerning his very extended remarks about my (and his) Fig. 4, he again accuses me of saying what is not in my paper and which I purposely avoided saying, as I knew long ago and published it, that the flux does increase; he evidently is not posted on what has been published, and his experiments were not necessary. What had misled so many physicists to giving the wrong answer, was the impression which the old law gives, and which I think is even stated in those words in some books (as is admitted above by Prof. Kennard) and by some teachers, is that "a circuit tends to expand" which are the words used in my paper. It was therefore not I but others who had "jumped to the wrong conclusions." That a circuit can "so arrange itself" that the flux *diminishes*, was clearly shown in the paper, as he will see if he reads it. His law needs a "patch" to make it fit; as he states it it is *not* a universal law.

The remarks of Mr. Mills, as also unpublished discussions of other progressive men who are versed in the new electron theory, are very encouraging. It seems that many of the proposed reforms suggested in the paper, fit in with the electron theory. "Thermal effects" do not necessarily enter into the experiments Figs. 3 and 6; the action is instantaneous.

Mr. Doherty, like others, has overlooked the decidedly "quantitative test" shown in Fig. 6, in which the longitudinal force was greater and opposite to the perpendicular force in which many physicists rely. He is evidently unfamiliar with the now classic Onnes experiment; the explanation which he says he "cannot fathom" is that the current was generated by drawing a single magnetic pole through the ring, as described in the paper. He has not proved that the deductions made in the paper "are wrong." I have replied above to the discussion of this experiment. To avoid the dangerous "jump to infinity" so ably discussed above by Dr. Mailloux, I have assumed that the temperature was only very near zero (as it actually was) and that the experiment was performed quickly. In reference to the general law proposed in the paper, he says I had assumed a "constant current;" he will not find this in the paper; he ought to have read it more carefully before making that statement.

Prof. Kennard says "Of course, in calculating the change in flux one must imagine the current to be kept constant." This is just what I claim should not be done when one is seeking the fundamentals. In my two ring experiment I have succeeded in separating the source (which ordinarily keeps the current constant) from the stored energy of the flux, and this shows (what no one has or can deny and what he himself proves) that the current (and therefore the flux also) diminishes when the flux energy is used up in doing work.

He refers to one ring; the "system" consists of two rings and they must, of course, be considered together as one system, as I did. I am pleased that he admits that "some text books make wrong statements" about a circuit tending to enlarge (my Figs. 4 and 5). In saying that "sliding contacts are a nuisance" he ought to have added, to the theorist who tries to make misfits fit (and to whom they are really a blessing); starting with better laws they drop out completely as a subterfuge; sliding contacts are extremely useful in practise. Apparently in order to meet the well known exceptions to the linkage law, he says "a circuit means a closed filament of matter." I differ with him decidedly, as I have shown in the paper some extremely important differences, which every student ought to be taught, between a "circuit" (as usually considered) and the "material" of the conductor. Moreover an e. m. f. can be induced in an open circuit, a straight bar for instance. To me it seems clear that a line of flux can vanish by converting its energy into mechanical energy, hence be unlinked (in effect) without inducing an e. m. f.; but this view may not yet be generally accepted. In his thought that physicists will never adopt the line-cutting conception for that based on linkages, he is mistaken as there are prominent ones who long ago have done so; students ought to be taught both.

I am quite willing to leave it to students whether my experiments are quite "as easy to explain" by the old laws as by the proposed new ones. Surely no one but a "heretic" would ever have thought of making these experiments (which even opponents admit are interesting) and in every case the results were as predicted. I repeat here what I have often said before, that if

a teacher, who is responsible for what his students have learned, were to ask them what would happen in some of these cases, they would probably give the wrong answer or none at all. In questioning the validity of Newton's third law, I think Prof. Kennard has few if any followers. I admit having "blind dogmatic faith" in this law. His explanation of the forces in Fig. 9, are contradicted by the facts. In not accepting the longitudinal force he differs with many others, including more especially some noted French physicists, like Ampere, Mascart, Joubert, etc. When he says that Fig. 8 can be explained by the pinch effect, he shows that he has not read the paper or does not understand the pinch effect, as the observed motion of that chain is in the *reverse* direction to that which would be produced by the pinch effect. In conclusion he seems to intimate that I have not been trained "in habits of exact and consistent thought." As I have also been accused of exactly the reverse (being too exact and consistent in interpreting the old laws), I leave the verdict to the students and engineers who may read the paper.

In conclusion, now that these proposed reforms have been thoroughly discussed, some of them for years, the engineer and the student may form their own opinion as to whether they find the new or the old more useful, direct, correct, reliable and less misleading. In some respects, the choice is a matter of opinion. With liquid conductors, like in electric furnaces and in electrolysis, in which these forces have greater freedom of action than in solids, the new method will be found to be far more helpful and reliable. The open minded progressive student may find interesting departures in new fields formerly closed to us.

Those interested in the subject of this paper will find some additional matter in a note on "Magnetic Flux Around a Conductor," by Carl Hering, A. I. E. E. JOURNAL, May, 1923, p. 519.

Discussion at Spring Convention

SOME FUEL DETERMINATIONS MADE ON LOCOMOTIVES OPERATED BY THE SOUTHERN PACIFIC SYSTEMS[1]

(BABCOCK), PITTSBURGH, PA., APRIL 25, 1923

Cary T. Hutchinson: There are several deductions from the test data with which I am not in entire agreement. These concern the method of analyzing the data rather than the routine of the tests, of which I have no knowledge other than given in the paper. Using the data presented by the author, I am led to certain results which do not agree with his; possibly some of these can be charged to the small scale of the diagrams presented in the paper and others possibly to my failure to understand the method of presentation. It seems worth while to call attention to them, if only to bring out an explanation.

The author says (p. 338) "wherein the curve (of Fig. 5) as drawn has been adjusted to give fuel requirements for constant speed." This, I believe, is the only explanation of the method of constructing this curve and it is not at all clear to me just what is meant by the sentence.

The curve is straight in its upper branch. This means that the oil-rate in gallons per thousand ton-miles (abbreviated *M-t-m.* herein) is a minimum at maximum values of tractive force. The equation of this line is

$$G = \text{gal. per } M\text{-}t\text{-}m. = 1.3 + 0.78 \text{ lb./ton} \qquad (1)$$

For a 1 per cent grade and 7 lb./ton, this gives $G = 22.3$.

This form of equation cannot be correct since at maximum tractive force the engine is working at maximum cut-off, and necessarily at higher steam rate; the curve should be concave towards the x-axis.

Equation (1) represents the author's conclusions with respect to the oil-rate at constant speed. Presuming it for the moment to be correct certain deductions follow:

For oil weighing 8 lb. per gal. having 18,000 B. t. u. per lb. equal to 144,000 B. t. u. per gal. the equation connecting oil rate and thermal efficiency is:

$$e.n = 2.37 \qquad (2)$$

where n = gal. per kw-hr. and e = thermal efficiency in per cent.

The equation connecting tractive force, or any force, and the work done per mile by that force is:

Watt hours per mile = 2 × force in pounds and in the present case

$$K = \text{kw-hr. per } M\text{-}t\text{-}m. = 2 \times \text{lb./ton} \qquad (3)$$

From equations (1) and (3)

$$G/K = \text{gal. per kw-hr.} = n = 0.39 + 0.65/(\text{lb./ton}) \qquad (4)$$

This equation gives for the maximum value of n, 0.39 gal. and the corresponding maximum efficiency 6.08 per cent. For lb. per ton = 53, the maximum value found in the tests, n = 0.40 and the efficiency = 5.93 per cent.

The author, however, on page 338 deduces a maximum thermal efficiency of 6.41 per cent; the reasoning followed in deducing this figure is, in my opinion, erroneous; it gives the thermal efficiency of the increment load and does not carry with it any allocation of the no-load losses. It is, therefore, not correct to say that it represents the thermal efficiency of the engine under any conditions. The actual maximum thermal efficiency, based on the author's curves, is about 5.93, 0.5 per cent less than the figure given by the author; this "maximum," referred to draw-bar, becomes 4.45 per cent as explained hereafter.

The author says (p. 339) "the over-all efficiency determined by this test was 5.57 per cent. It is the ratio of the integrated foot-pounds of work done by the engine whenever the draw-bar pull was positive, to the total energy in the fuel used over the same time. Apparently it is constant for all grades greater than 0.5 per cent."

As already explained, the curve of Fig. 5 is not based on constant efficiency, but on efficiency increasing with tractive force. For an 0.5 per cent grade the efficiency is 5.57 per cent; for 1 per cent grade, 5.7 per cent, for 2 per cent grade, 5.85 per cent. The author does not give the derivation of this value 5.57 per cent as the average, but it may be taken to represent the average thermal efficiency when the engine is doing work, based on the oil used during those periods, eliminating all oil used at terminals and also all oil used when the tractive force is negative; this efficiency is referred to the rim of the driver and not to the draw-bar. Using this value and the equivalent grades, the author, in Table V, parts 2 and 4, computes the oil consumption when the engine is doing work, and from other tests adds the oil used when the engine is at terminals or drifting. Using these tables I find the following:

	East-bound	West-bound	Both
Total oil, for positive tractive force......	1550	547	2097
" " stand-by and negative t. f......	291	409	700
" " for the run..................	1841	956	2797

The thermal efficiency, based on total oil used referred to drivers, is then

$$5.57 \text{ per cent} \times 2097/2797 = 4.17 \text{ per cent}$$

But, the only efficiency that is significant in a comparison with electric drive or with any other form of motive power is the efficiency referred to the draw-bar. The locomotive is a machine to do the work of hauling a given load. This work is measured at the draw-bar behind the tender. If one form of motive power

1. A. I. E. E. JOURNAL, 1923, Vol. XLII, April, p. 335.

is intrinsically heavier or less efficient, this should be charged against it in any comparative statement.

From the data given, the train with the tender about two-thirds loaded is 250 tons engine and tender, 750 tons trailing. The efficiency at the draw-bar then becomes

$$4.17 \text{ per cent } \times 0.75 = 3.12 \text{ per cent}$$

Similarly, the maximum efficiency when referred to draw-bar is

$$5.93 \text{ per cent } \times 0.75 = 4.45 \text{ per cent}$$

The test results then give an average efficiency, measured at the draw-bar, of 3.12 per cent, equivalent to 109,000 B. t. u. per kw-hr. This is the result of test runs, and there can be no doubt that the average results under service conditions will not be as good. If the fuel under service conditions be assumed about 15 per cent more than under test conditions, a conservative estimate, the average use corrected to service conditions, is 125,000 B. t. u. per kw-hr. at the draw-bar. This is equal to 10 lb. of coal of 12,500 B. t. u. per lb. The corresponding thermal efficiency is 2.72 per cent.

In a word, assuming the author's fundamental result, "5.57 per cent over-all efficiency," the correct statement of this result is an over-all thermal efficiency at the draw-bar of 3.12 per cent with a maximum of 4.45 per cent.

A very different picture!

There are apparently several slips in the text of the paper; for instance: The author says (p. 338) "at constant speed would be 10.25 gal." This does not correspond with curve which shows a consumption under the conditions stated of approximately 8.0 gal. instead of 10.25.

Again, on page 338, second column, is the following: "and for a 1 per cent grade, 23.3 gal." I find from the curve, 22.3 gal. This is a material difference, as it changes one of his fundamental data from 14.7 gal. to 15.7 gal., and also changes the figure for the total resistance given at the top of first column of page 339 from 11.7 lb. to 8.4 lb. This, of course, necessitates changes in the deductions in the next paragraph and in other places.

I am unable to check Fig. 6, using the data given by the author. For the oil in question, having 144,000 B. t. u. per gal., a 5.65 per cent thermal efficiency is equivalent to an oil consumption of 0.42 gal. per kw-hr.

The formula for kinetic energy is

$$\text{Watt-hours per ton} = \frac{(\text{Miles per hour})^2}{40} \tag{6}$$

and hence

$$\text{Gal. per } M\text{-}t\text{-}m. = 0.42 \times \frac{\text{M. p. h.}^2}{40} \tag{7}$$

This gives 26.2 gal. for 50 m. p. h. instead of 27.74. The entire curve is somewhat off.

The figure 259.7, in the last column of Table V, part 4, should be 359.7. The addition of the column is correct.

I do not understand why the point Q of Fig. 5 should not be on the curve; precisely the same argument applies to Q westbound as to H, eastbound.

These are all of minor importance.

The electric drive to replace this steam service would be a 4-axle, 110-ton electric locomotive for 750 tons trailing weight; at 15 m. p. h. on the limiting grade, the input to the locomotive will be less than 2000 kw. If the efficiency from power house to locomotive drivers is taken at 63 per cent (the author assumes 70 per cent in an earlier paper) the ratio of power at draw-bar to power house will be $0.63 \times 750/860 = 0.55$.

This section is ideal for regeneration and, as a matter of course, it would be availed of. The comparative figures for the energy used are given in Table I. The calculations of work done are based on the data given by the author for elevations and curvature, with 7 lb. for track resistance.

TABLE I
WORK DONE AT DRIVERS, STEAM DRIVE

		East-bound		West-bound
1. Weight of train tons		1000		1000
2. Work at drivers kw-hr.		3700		1250
(a) Grade	2760		985	
(b) Curve	250		25	
(c) Track	690		240	
3. Available for regeneration (a) − (b + c)		1820		720
4. Deliverable to contact system (75%)		1365		540
5. Deliverable at driver (80%)		1090		430
6. At driver as per cent of total work		29.4%		34.4%
7. Same, for round trip, same tonnage both ways			30.6%	

Assuming then that 30 per cent of the total requirement is furnished by gravity and 70 per cent by the power station, the relative energy requirements for a round trip are:

TABLE II
RELATIVE HEAT REQUIREMENTS STEAM AND ELECTRIC FOR SAME SERVICE

		Steam	Electric
1. Weight of train	Ton	1,000	860
2. Energy at driver, total	Kw-hr.	4,950	4,250
3. " " " from oil	"	4,950	2,970
4. " " " " "	%	100	60
5. Heat required at draw-bar per kw-hr.	B. t. u.	109,000	45,500
6. Total heat required	$10^6 \times$ B. t. u.	540	135
7. " " "	%	100	25

This means that in comparison with the author's test result, electric drive would reduce the fuel required by 75 per cent—a ratio of steam to electric of 4.

If allowance be made for the difference between test and service conditions this ratio will be even greater.

These results are in practical agreement with the estimates of the Super-Power report.

N. W. Storer: Now, I think Dr. Hutchinson has struck some of the very points that I had in mind. In the first place, the train friction, train resistance, is a variable quantity as every one knows. We know it is lower at low speed than it is at high speed. Seven pounds per ton seems to me to be too high to assume for the train friction over that entire line, and then, too, the attempt to find the locomotive friction is taken as the difference between two per cent and one per cent grades.

Well, that assumes identical conditions of train resistance and of locomotive efficiency for the two grades. We know that they were running at different speeds, and therefore, at different efficiencies, and different amounts of power required for train resistance.

W. J. Davis, Jr.: The tests of the oil burning Santa Fe type of locomotive as carried out by Mr. Babcock are particularly interesting and valuable because of the accuracy of the methods used and the detailed analysis of fuel required for the various demands of the locomotive before and after being called for duty.

It is to be hoped that further tests may be made on other types of locomotives such as Mallet compounds, Mikados and Pacifics and under a wider range of operating conditions.

The results of these tests appear to be materially better than would be expected from a coal burning locomotive; due possibly to the elimination of cinder losses, which often exceed 10 per cent in heavy grade work, improved adjustment of the air supply and closer regulation of the steam pressure. The superiority of oil over other kinds of fuel is even more marked in railway work than in central stations which are under no restrictions as to

methods of handling the coal or regulating the firing and steaming conditions of the furnaces and boilers.

The paper is opened with the statement that "one of the principal arguments advanced in favor of electrification is the large saving in fuel sure to result therefrom." While the item of fuel consumption is undoubtedly important in making a detailed comparison of steam with electric power, it is doubtful if this feature has proved a controlling factor in any electrification so far carried out in this country. Although of considerable magnitude, the saving in fuel is usually offset by the fixed charges, maintenance and operating expenses of power house, substations, transmission line and distributing system, so that as a rule, there is just about an even break between the cost of electric power and the cost of locomotive fuel.

The most important reasons for electrification are, that it is the most reliable; the most flexible and under certain conditions, the least expensive in capital cost of all available methods of transportation. The absence of any practicable limitations to power requirements as expressed in terms of tractive effort and speed, permits large increases to be made in the capacity of existing tracks with material reduction in train and engine crew wages and particularly in the cost of overtime. The greatest saving however, will be found in the item of locomotive repairs in which the cost for the electric locomotive is usually about 1/3 that of steam.

The freight traffic of the railroads is increasing at a rate of between 7 and 8 per cent per annum which results in doubling the tonnage to be handled in 12 to 14 years. By a gradual adoption of electric power, provision for handling this future growth may be made for a less capital investment than would be possible with steam power, and the savings in operation by reason of reduced locomotive maintenance and transportation expenses will amount to 12 to 18 per cent of the net cost of electrification. Expressed in terms of the three principal items of operating expenses, namely: Maintenance of Locomotives, Maintenance of Way & Structures and Transportation Wages, the saving will amount to 25 to 40 per cent. It is these factors rather than fuel saving which it is believed will finally bring about the electrification of our more important railroads.

W. I. Slichter: We have in this paper what is probably the most accurate analysis of fuel consumption in railway work and also probably an example of the most efficient use of fuel in railway experience. It shows that in burning fuel oil under a boiler a thermal efficiency of six per cent was attained.

Our geological authorities have made a report to the U. S. Government that our known oil resources are just sufficient to last fourteen years at the present rate of consumption. With this exhaustion of our resources facing us it is a question in which every citizen of the country is interested as to whether it is wise to use our oil at this low efficiency when it is needed for internal combustion engines where it can be used so much more efficiently and particularly, when electrification would not only make possible a more efficient use of this fuel but would make it possible to use sources of energy which are less limited, such as coal and water power.

F. E. Wynne: Mr. Babcock's paper is a valuable addition to engineering knowledge. He shows how methods of analysis, more or less familiar to electric railway engineers, may be applied to steam locomotive fuel tests to determine the proportion of fuel used for each of the several portions of the operating cycle. The test data and derived results should be especially welcome to those engineers whose duties require them to make comparison of the costs of electric and steam operation. Also, the method may be applied to determine fuel costs for a portion of a division where the railway's records show only the division total.

A most commendable feature of the procedure was the selection of engine 3614 because it had a record of "average fuel performance." The assumption is that this engine gave such performance in comparison with other engines of the same class operating between Bakersfield and Mojave. Reference is made to the engine's being prepared for the test. It would be interesting to know what this preparation comprised, that is, was the engine placed in average operating condition, or was it brought up to the best possible mechanical condition prior to the tests?

Another praiseworthy feature is the correction of train weights during the runs for fuel and water consumed, in order that ton-mile figures may be accurate. This precaution is sometimes overlooked in tests. It is stated that the basic train weights were taken from the yardmaster's reports at the initial points. It would be interesting to know whether we are correct in assuming that these were scaleweights. Mr. Babcock states that a complete record of fuel burned by the locomotive was taken, including both that charged to engine-house service and that charged to road service. He further states that only the fuel charged to road service is taken into account in determining the "Operating Efficiency-Fuel." While the use made of these values of operating efficiency is legitimate, it is important to remember that the fuel charged to road service does not tell the full story of the fuel-consuming ability of the steam locomotive. For example, the average value of 92.5 per cent given in Table IV is checked by Table V for the period designated in the caption of Table IV. However, inclusion of the fuel burned in "firing up," while "standing by" waiting for crew, and all of that consumed between the engine's arrival at the terminal and its delivery to the engine-house, (as shown in Table V), reduces this ratio to 84.7 per cent.

The foregoing items are important in comparing the performance of steam and electric locomotives.

It is stated that Operating Efficiency-Fuel "is a measure of the operating efficiency of the division organization." This statement appears too broad for the value of this ratio is dependent chiefly upon the amount of standing time at terminals and on the road while efficient operation requires that engineering maintenance. etc., as well as dispatching, be efficient.

It is conceivable that the Operating Efficiency-Fuel might be high during a period of little traffic, although the operating efficiency of the division as a whole might be suffering from poorly applied and inadequately maintained motive power, bad firing, uneconomical train make-up, etc. Or, as applied to individual trains, one train may be given preference without cause and show 96 per cent of its total fuel burned in moving the train and, at the same time, this may result in highly inefficient operation through the imposition of extra stops on other trains, the production of crew over-time on drag freight trains, etc.

It is stated that "speeds were determined by counting engine driver revolutions." Presumably, no driving wheel slippage, (except in starting), was encountered during these tests. Where a locomotive is operated at running adhesions such that the drivers slip at times, a more satisfactory method of determining speeds is by counting idle wheel revolutions.

Train resistance is an elusive subject. It is dependent upon so many variables that its value is difficult to determine. The paper develops 4700 pounds as the internal friction of the locomotive, that is, 27 pounds per ton. When the assumed 7 pounds per ton for rolling friction is added, the total locomotive resistance becomes 34 pounds per ton, which is consistent with determinations made for steam locomotives elsewhere.

The exposition in connection with Fig. 6 presents a point which, although well known, is too often overlooked, that is, the fuel-saving value of drifting to the greatest extent possible under the requirements of the schedules. Fig. 6 is based on a constant overall thermal efficiency from standstill to 50 miles per hour. There is some doubt as to whether the use of constant efficiency is justifiable over such a wide range of speed. Data derived from Fig. 5 do not check very closely with Fig. 6. For example, from Fig. 5 the fuel cost of accelerating a 1000-ton

train from rest at Kern Junction up to a speed of 38 miles per hour at Magunden is 6.04 gallons of oil per 1000 ton-miles and the distance is 3.4 miles, giving a total fuel cost of acceleration of $3.4 \times 6.04 = 20.54$ gallons. At 38 miles per hour, Fig. 6 shows 16.3 gallons; hence, the efficiency of acceleration in this instance was apparently $16.3/20.54 \times 5.65 = 4.48$ per cent.

From Magunden to Edison, the fuel saved by using a part of the kinetic energy of the train in slowing down from 38 to 30 miles per hour was 4.32 gallons per 1000 ton-miles (from Fig. 5), and the distance is 3.1 miles, showing a total fuel saving of 13.39 gallons of oil. By Fig. 6, the fuel-saving is 16.3 minus $10.0 = 6.3$ gallons. Hence, Fig. 5 indicates that in this instance the fuel-saving corresponded to an efficiency of 2.66 per cent.

Similarly, from Edison to Flag No. 1, Fig. 5 shows a total saving of 21.35 gallons, while Fig. 6 shows only 2.8 gallons, so that the fuel-saving of Fig. 5 corresponds to an efficiency of 0.74 per cent.

The closing paragraph of the paper carries a recommendation for further similar tests in other classes of service and with other types of locomotives. This recommendation should be heartily endorsed by all railway engineers, as accurate information regarding locomotive performance is all too meager.

A. H. Babcock: The trend of the discussion makes necessary an explicit statement that the paper is the record of a study of fuel consumptions of a locomotive *in service.* The purpose of the study was to obtain information for use by the operating officials in their fuel conservation work: hence, every precaution was taken to test under strictly service operating conditions.

Accurate fuel performance records are kept of the fuel performance of every engine on the system. Reference to these records showed that the No. 3614 was an "average performer," and for this reason it was chosen for the test. Offers to reset valves or to make adjustments of any other kind on the engine were declined.

The only preparation of the engine permitted was to install a small fuel oil tank, a pump—to maintain constant level in the tank,—and the oil meter; all of which was necessary because the engines use gravity feed burners, and the available head was insufficient to force the oil through the meter to the burner.

Very explicit requests were made that there should be no special consideration on the part of the dispatcher or of other officials in helping the test trains over the track. Every effort was made to impress the division officials that the test was not to be in any sense a special performance, but strictly on service runs. Furthermore on all of the nice record trips a different start engine crew manned the engine. In other words, this paper records service operating conditions as nearly as possible as they can be determined.

The train weights given were not scale weights, but were the bill of lading weights plus the tare marked on the cars.

The record given, in the paper is, then, merely that of an especially careful determination of service performance without any attempt to make comparisons; precisely as the scientist publishes the results of his research, leaving to others the practical application thereof in the analysis of their special problems.

For these reasons it is entirely proper for Dr. Hutchinson to make any application of these figures he pleases; and to argue himself into any position whatever with reference to steam vs. electricity, or any other question. He may refer the efficiency to the drawbar or to any other reference point that fits his argument. In the paper it was referred to the wheel rims as being the one point at which the total work of the engine is done. Observe please in this case the distinction between "engine" and "locomotive."

Dr Hutchinson falls into several excusable errors because of the fact that the curve in Fig. 5 was somewhat modified in the reproduction, and also because of the failure to show the curve dotted between -0.5 and $+0.5$ grades. (See par. 2, col. 2, p. 338).

There is also another source of error, wherein Fig. 6 is a reproduction of a curve from one run only, whereas the figures in the text of the paper relating thereto are for the average of all runs.

His criticism of the shape and slope of the curve in Fig. 5 probably would not have been made had he realized that these locomotives are designed for most efficient operation at the load at which they are operated in this very mountain service; consequently the curve should show an increase in efficiency with increase in load up to their rated capacity. (See p. 341, last sent., col. 1).

His paragraphs 3 and 4 give an incorrect picture of the performance of a properly loaded locomotive, because his statement "necessarily at higher steam rate" implies that the engine efficiency "necessarily" decreases as its steam consumption increases; which can be true "necessarily" only with engines of poor design or when badly operated. The curve shows increased efficiency with increased load because they are well designed and are properly operated. A good engine driver "feels his engine" and operates at practically constant power by increasing speed where the grade permits. If he fails in this respect, he hears from the dispatcher. When the loading is increased beyond the economic point, the efficiency falls off, which is the reason why point "Q" is off the curve.

The adjustment of the curve to give fuel requirements for constand speed, (p. 338), may best be illustrated by an example. Suppose the train to enter a section of 1½ per cent adverse grade at 35 miles per hr., and to leave it at 20 miles per hr. Obviously the difference in its energy at the two speeds helps it over the section; hence the fuel equivalent of the energy difference must be added to the recorded fuel consumption. This correction reduces the fuel consumption to that of some constant speed, different of course for different grades.

He complains that in deducing the average efficiency no account is taken of oil used while standing on sidings or at terminals, or on assisting grades. Any application of this kind at once converts the question from a general to a special problem. The data given in the paper were segregated in such fashion that an engineer considering any special case can make accurate and precise application of the information, to any length of delay on sidings or at terminals or roundhouses, that may be necessary to fit his particular problem.

In the paragraph where he deduces an efficiency of 2.72 per cent all his argument falls to the ground when it is remembered that service conditions were recorded in the test, and not special test conditions. The "very different picture" he draws as a result of his studies may be turned into as many different pictures as he pleases, by special applications of the data; without disturbing in any way the fundamental fact that the information given him is merely a record of service operating facts, of general application.

His equations (**6**) and (**7**) will agree with Fig. 6, when he adds the usual 5 per cent for energy of rotating parts.

Point Q does not fall directly on the curve of Fig. 5 because the time card rating of the engine calls for a different load westbound from eastbound, and at this particular loading the engine was overloaded.

It is thought that if Mr. Storer will compare the method commonly used for determining locomotive internal friction with that used in the paper, he will come to the conclusion that the results given are more than usually accurate. Furthermore by changing the train resistance as given in the table, from 7 lb. to any desired figure, the locomotive internal friction can then be deduced for different conditions, with any desired degree of accuracy.

Mr. Slichter probably does not understand that the fuel oil used in the locomotives is the residue after the motor vehicle

fuel and lubricants have been extracted from the crude oil. In physical characteristics it is very like tar.

Mr. Wynne refers to the "operating efficiency-fuel" as a measure of operating efficiency of the division organization. A locomotive comes under the control of two separate departments in railroad organization: in the roundhouse it is a motive power machine until it passes the turntable; until it returns to the turntable it is under the control of the transportation department. It is easy to see therefore that if there is a tendency on the part of the two members of this organization to "pass the buck," one to the other, the "operating efficiency-fuel" may fall very low. The fact that on this division it is high indicates a maximum of cooperation between the two departments. While, by favoring the test train at the expense of the others, it might be possible to show high operating efficiency for a single run, or a comparatively small number of runs, it would be difficult to bring this result about for the eighteen trips recorded in the paper.

The author takes a significant satisfaction in noting that the most valuable comment upon his work, as recorded in this discussion, has been by those who have been over this district personally, and therefore are in a position to have better understanding of the facts. Mr. Davis, in particular, shows in his comment, the effect of an intimate acquaintance with operating conditions on the Pacific Coast, as they are.

SOME PROBLEMS IN ELECTRIC FURNACE OPERATION[1] (ANDREAE); IMPROVEMENTS IN FERRO-ALLOY ELECTRIC FURNACES OF HIGH POWER INPUT[2] (SAKLATWALLA AND ANDERSON); DEVELOPMENT OF THE LARGE ELECTRIC MELTING FURNACE[3] (HODSON), PITTSBURGH PA., APRIL 25, 1923.

J. A. Seede: I remember distinctly a large smelting furnace making ferro-alloys in which the condition existed that Mr. Andreae points out, *i.e.*, the charge surrounding the left hand electrode, looking at the furnace from the transformer, indicated that the temperature was too low to produce the required metallurgical action while the charge around the other electrodes indicated that the temperature was high and the metallurgical conditions satisfactory. Such unbalanced metallurgical conditions never produce satisfactory operation and no one had made, or has made to my knowledge, such a thorough analysis as the author has made in this paper.

One plausible reason has been suggested why the electrodes in electric furnaces do not operate equally and that has to do with the manner in which the furnace is charged. It is evident that if the furnace is not charged properly and an excessive amount of coke happens to be thrown around one of the electrodes the result is equivalent to inserting a resistance between the electrode and the charge which prevents the power being concentrated around the end of the electrode and while the same amount of energy may appear as heat around that electrode it will be diffused over a large area and the temperature gradient will be so low that no metallurgical action may result.

I am quite sure we are all much interested to read his analysis of the conditions in the electric furnace and it is astonishing to note the difference, where in a furnace taking a total of 2600 kw. there was a difference of 620 kw. between the input to electrodes No. 1 and No. 3. The suggestions for balancing the power input to the furnace are very interesting but it is not quite evident how a practicable arrangement can be developed as is shown in Fig. 6.

In Mr. Hodson's paper a rather general statement is made about induction furnaces. We know the induction furnace has not been 100 per cent successful in its application to the melting of iron and steel in the past but that does not necessarily hold for the future and I am looking forward to the time when, for certain applications in this line of work, it will be a successful competitor of the arc furnace.

W. E. Moore: In discussing Mr. Hodson's paper on a 50-ton Greaves-Etchells electric furnace as designed for the Ford works:

Perhaps the greatest limitation in both the design and operation of electric steel melting furnaces is the weakness of the refractory linings.

If a refractory lining were known or could be developed that was ideal as regards resistance to fusion, heat insulating properties, resistance to slags and resistance to cracking, it would then be possible to design an electric furnace in a great many different forms, shapes, and arrangement of electrodes and embody operating features that are not now practicable with the best refractories known to the art.

Such ideal refractories would make the matter of electric arc furnace design quite simple, but unfortunately in furnaces for the manufacture of steel the working temperature of the furnace is so near the critical temperature of the refractories that the refractory problem alone very largely controls and limits the design of the furnace.

The electrode is also a very weak element of electric arc furnaces. If we had ideal or perfect electrodes, the problem of furnace design and operation would also become much more simple. However, the best available materials for electrodes are carbon or graphite. These electrodes are relatively weak mechanically, comparatively poor electric conductors, comparatively high heat conductors, subject to irregularities and shrinkage in manufacture and are readily oxidizable and fairly expensive. Although their limitations are pretty well understood, nothing else is known commercially to take their place.

It is not believed, however, that the size of the three-electrode arc furnace is limited to 30 or 40 tons, as stated in the paper; in fact with 24-in. electrodes it is quite possible to build and operate successfully furnaces having only three electrodes that are very much larger than 40 tons and, furthermore, the 24-in. electrode is by no means the limit in size of the carbon electrode. Electrodes 32-in. in diameter are in quite successful operation and, furthermore, there is the self-baking type of electrode which is not limited as to size, especially when confined to the use of stationary type furnaces such as smelting furnaces.

The wear of electrodes or loss of weight does not seem to be due, except in a minor degree, to the amount of power passing from the electrode into the furnace charge, but is almost entirely in proportion to the amount of electrode surface exposed to oxidization losses in the high temperature zone of an electric furnace.

Since the exposed surface of the electrode is proportionate to the diameter of the electrode and to the length exposed to the high temperature zone, it is desirable to limit the diameter to the minimum which will successfully carry the required current and keep the length exposed to heat as short as possible. The area or electric carrying capacity of the electrode being proportionate to the square of the diameter and the oxidizing surface varying only as the diameter, it is evident that a more economical arrangement is one in which the smallest number of electrodes are used of a diameter only sufficient to properly carry the current: thus the power can be most efficiently brought into the furnace on a minimum number of electrodes rather than being divided over a larger number of smaller diameter.

It is therefore evident that in order to reduce electrode costs there should not be a multiplicity of electrodes.

The arrangement of an arc furnace by which the number of electrode groups is multiplied is consequently moving in the wrong direction. A lower electrode consumption can always be

1. A. I. E. E. JOURNAL, 1923, Vol. XLII, May, p. 498.
2. A. I. E. E. JOURNAL, 1923, Vol. XLII, August, p. 775.
3. A. I. E. E. JOURNAL, 1923, Vol. XLII, June, p. 600.

obtained by using the minimum number—three (if a 3-phase power system is to remain balanced under all conditions).

In fact, the ideal arc furnace in so far as electrodes alone are concerned, would be a one electrode one-phase-bottom-contact electric furnace. However, the power companies will not stand for any considerable load being supplied from a single phase of their three-phase power systems and it has been shown to be practically impossible to carry any considerable current through conductive refractory bottom or hearth of any size suitable for ordinary volumes of work or rapidity of operation, since refractory bottom materials, being a source of uncertainty, give continuous trouble wherever it is attempted to carry current of volume through conductive bottoms in steel smelting furnaces.

There is another point in the design of the large furnace described in this paper which is subject to wide criticism. In the paper great advantage is claimed for the conductive hearth or bottom carrying one phase of a three-phase transformer group for each group of electrodes. As a matter of practical experience, well known to steel furnace operators, the attempt to carry any considerable volume of power through a conductive hearth results in repeated trouble and loss. When cold the hearth has relatively no electrical conductivity and therefore the furnace must start as a single-phase furnace—giving a slow and wasteful start. When the hearth gets hot, its conductivity increases, that is to say, the refractory materials become pyroconductive: in other words the bottom materials have a negative temperature coefficient. This causes the current to center in hot spots, still further increasing their temperature and making a streaky and unstable distribution of current in the bottom, resulting in channels melting through and causing the hot metal to reach the shell and burn its way through the shell causing what is known as a "cut-thru"—a dangerous and vastly expensive occurrence.

However radical the designer of the 50-ton furnace may be or however bold and courageous as to developing a larger size, he nevertheless seems to have been very careful in one way: *viz.*, he has put a false refractory roof under the furnace to catch the molten steel, liquid slag, etc. from the "cut-thrus" which he is fearful may follow as a result of putting much power through the furnace bottom.

I recently became acquainted with a furnace carrying one phase through the bottom, in which "cut-thrus" had been frequent, finally the hot metal cutting off the tilting screw and allowing the entire furnace to topple over into the ladle pit. It is understood that that furnace is being changed over to cut out the bottom conductive feature and put all the electrodes on top, extending through the roof.

For the peculiar transformer—electrode connections on the furnace described in the paper—great claim is made as to the accuracy of the balance of power between the three phases on each electrode group. It seems evident, however, that the power is not equally balanced on the three phases of each electrode group.

The peculiar transformer arrangement described might be known as an un-symmetrical star-connected three-phase system in which two transformers are of one size and the third (connected to the furnace hearth or bottom) is of a smaller size, developing practically the same current at a lower voltage. It is evident that a perfect balance cannot be obtained under all conditions unless the three phases were equally loaded. Since the smaller transformer works through the variable resistance of the bottom or the hearth, and since the hearth resistance varies inversely with the temperature, the load on the small transformer is consequently a variable and unregulated factor in this total load. Also it is evident that the bottom, being non-conductive when cold, must be heated by gas or by the two top electrodes of the group running single phase before the bottom will pass current of any appreciable quantity. After the bottom becomes hot there is a tendency for the temperature to continually rise and its resistance becomes lower, so that it tends to "hog" the power from the low-voltage leg of the three-phase system and unless that effect be counteracted in some way it produces an unstable and unbalanced condition. The current flow through the hearth can, of course, be limited by installing higher reactance in that phase, but that also means unbalanced power factor.

It must be admitted, however, if in a given furnace the number of electrode groups be multiplied and a different phase of each group be connected to the bottom, that the load and power factor of the multiple group may then be practically balanced, but the expense and disadvantage and high electrode consumption and other losses of the multiplicity of electrodes makes such multiplicities entirely undesirable.

The design embodying a multiplicity of electrodes to allow the claim of distributed heat, seems to be a distinctly backward tendency because it is very important to keep the arcs as far away from the furnace walls as possible, the refractories being the weak part of the furnace.

The "hot spots" between the arcs should be limited to the center of the furnace and, as far as possible, away from the side walls. By so doing the "hot spot" in the bath may be run at higher temperature without injury to the refractories, permitting more rapid formation of carbide, quicker work in deoxidizing and refining the charge.

This single group of three electrodes is only another good reason for building the furnace in a cylindrical shell, other reasons being the better support by arcing-in of the refractories, smaller amount of surface exposed to radiation, and the more easy working of the charge due to avoidance of sharp corners to fill with slag and cause inefficient drainage of the furnace.

In short, the design of the large furnace described appears to violate many of the best known principles of electric furnace design and construction and varies so far from present good practise that it is believed that the furnace will probably never be completed or, if completed, will not be practical in operation without radical changes.

Edward T. Moore: In regard to the last paper of Mr. Hodson: A resistor when acting as such, is subject to deterioration. It does not make any difference whether it is an air heater or, acting as it does, in the hearth of a furnace. The refractory material, however, in the bottom of an electric furnace depends upon the care given to it while in service. With proper material and competent attention and repairs, little trouble should be expected from a bottom conducting furnace.

The regulators would be adjusted for regulating the amperes or voltages or combination of both and should be able to take care of any reasonable unbalance which may inherently be in the circuit. The instantaneous unbalancing might be considerable, but the average unbalancing, I think, will even up, and I am afraid a representative of a central station reading this paper, not being familiar with the operating conditions, may misconstrue the author's intentions because, after all, it isn't the small amount of unbalancing of the circuits which is detrimental to the central station; it is more the fluctuation of the load itself.

With reference to the second paper by Mr. Saklatwalla the means of regulation by the watt meter principle on the furnaces upon which he is working, I think are necessary, but I would not want it inferred, when it comes to steel furnaces in general, that this is necessary or even desirable. The regulation by the current method seems to be working out very satisfactorily; in fact, experiments conducted by using a Kelvin Balance alongside of the common regulator does not show any particularly improved results.

In regard to the last paper by Mr. Hodson, a resistor, when acting as such, is subject to deterioration. It doesn't make any difference whether it is an air heater or acting as it does in the hearth of the furnace; therefore, of necessity, the refractory material in the bottom of the furnace is bound to disintegrate,

caused by such current conduction. I think this is borne out by inspection of the hearth of any bottom conducting furnace.

The reference made to the induction furnace I don't quite agree with. Of course, we know that the induction furnace at first developed faster than the arc furnace; following Colby's suggestion in 1887, but due to its limitations, especially in regard to the fact that low frequency was necessary, the induction furnace didn't develop very fast; in fact because of these limitations the arc furnace, following Siemen's experiments in 1878, received a very great development, and the induction furnace was practically lost sight of.

However, with the advance of the art and ability to provide low-frequency current in a reasonably efficient way, small units of the induction furnace type have been very successfully developed and are giving very good results, and I believe, and I am confident, that induction furnaces of very much larger capacity will be developed and will operate successfully compared with arc furnaces, because for one thing they use no expensive electrodes. Also the refractory situation is very much more satisfactory.

F. W. Brooke: The author makes many *operating* comparisons between so-called large three-electrode furnaces and "large" Greaves-Etchells furnaces.

Good comparisons can only be made on similar practises such as let us say the American practise of electric steel making.

It would therefore be interesting to wait until such a comparison is available. At present the writer knows of several three-electrode furnaces that have given very excellent operating results on charges of 50-ton capacity in furnaces of nominal capacities of 30 and 40 tons, but he does not know of any furnaces operating or that have operated on the Greaves-Etchells system in America that have a nominal capacity which exceeds 6 tons.

It is also somewhat misleading to state that large Greaves-Etchells furnaces can be changed from bottom heating system to the top electrode system "by change of switch", which at least infers that the insertion of one switch does the trick. Electrical engineers would be far more interested, and better able to judge by being shown the difference between the wiring diagrams of a simple large electric furnace and the wiring diagrams of a "change-over" large Greaves-Etchells system.

The American steel maker will often put up with small compromises in order to obtain all round simplicity and strength, and a short review of what such a compromise might be (if any) by the use of the top electrode system as against, let us say, the Greaves-Etchells system described in this paper may be of interest to the reader.

1. Complicated electrical apparatus has already been suggested.

2. As the author states, in the secondary windings of each bank one phase has different characteristics to the other two and therefore calls for a special transformer and two spare units instead of one in cases where spare windings are carried.

3. Eight electrodes where six could easily have been used, introduces complications well known to designers and operators.

4. The value of bottom heating, if obtainable, is too well known and appreciated to further discuss. What the practical steel maker is interested in however, in any particular furnace such as the Greaves-Etchells is, how much bottom heating will I obtains? And what will it cost to obtain it?

The author unfortunately did not give any data (which can be very easily obtained) giving the proportionate amount of "bottom heating" in the Greaves-Etchells furnace. From actual tests carried out during furnace operation this "bottom heating" was found to be so very small that it can never justify the compromises it involves.

5. Restriction to the use of basic operation only. Many attempts have been made to operate a conductive bottom furnace on the acid process but without any success, and it is an accepted fact that present day acid refractories will not conduct the secondary current used in regular electric furnace practise. It is this feature which has done away with many bottom connections, and has made furnaces such as the Greaves-Etchell furnace look "for some other way" for the current to flow. In the latter case it has brought about a practical condition which the author himself states when referring to a competitive furnace as being "one of the objections."

It is interesting to note the fundamental principles which have so far prevented any real success in bottom heating in electric furnace practise.

In the first place it is an unfortunate fact that materials which are electrically conductive are also thermally conductive. Therefore any furnace hearth which is in itself conductively electrical, will also dissipate heat more readily and give a high power consumption.

Secondly, as already stated, only basic bottoms can be made to be conductive and once more it is unfortunate that basic refractories at their present development will only stand up at their very best the heat from a steel bath and any external heat such as "bottom heating" will rapidly effect their life, especially when put in under the condition employed by the Greaves-Etchells system. It is here interesting to note that the writer in his endeavor to improve this condition once put in a 6-ton basic lining in the standard "burnt-in" way and soon found it was non-conductive and had to be torn out.

If the power represented by the "bottom" phase of a Greaves-Etchell system were all converted into heat and this heat applied as bottom heating then the lining would not stand up for one single melt.

It will be noted in Fig. 4 that the designing engineers saw fit to put a double refractory lining underneath the furnace lining proper, which is referred to as a double lining with an air space between.

Reference has been made to balanced electrical load being obtained for any hearth resistance. This would be quite possible in the Greaves-Etchell system if the hearth resistance were known, but this hearth resistance is not only unknown when the transformers are designed but varies to such an extent that the drop across the bottom ranges from 5 volts to the full impressed voltage even in one heat, and it is easy to see that when the latter is the case the bank is operating under single-phase conditions, while this is the extreme condition, there is also the every day condition of constant hearth resistance variation and each bottom varying according to how it is put in and kept up. What then is the use of a mathematically proved balance (by vector diagrams or otherwise) when any proof presupposes a known resistance?

If any furnace gives a presupposed mathematically correct perfect balance it is surely the simple top electrode furnace where we have three phases all alike, and where the only upsetting features are due to regular furnace design and steel melting practise and these features are common to all furnaces.

E. B. Dawson: In regard to Mr. Hodson's paper, I think that possibly a little data in regard to the voltages that are used on the 60-ton furnace might be of interest. Mr. Hodson states that furnace users have transformers with a capacity of 12,000 kv-a. That 12,000 kv-a. is divided into four 3000 kv-a. units. The 3000 kv-a. units are further divided into three single-phase units, all the three units mounted in the same tank. The two units which supply the top electrodes have a capacity of 1150 kv-a. with a maximum low voltage of 90 volts, with taps in the high-tension voltages to give reduced volts of seventy and fifty. The short leg has a capacity of 700 kv-a. with a maximum voltage of thirty-nine volts, and taps in the high-tension for reduced voltages of 32 and 25.

It might be noted in connection with Mr. Hodson's statement regarding reconnecting the transformers to operate with an acid bottom that such reconnections necessitate the use of a separate

transformer for each set of two top electrodes which is the reason that they have the four transformers here for this furnace.

F. V. Andreae: Answering Messrs. Seede and Moore, I am aware that some of my suggestions for balancing the loads of the three electrodes are rather unsatisfactory from the point of view of the power companies.

My aim was to put the whole problem on a solid mathematical basis, and to show how the equations could be interpreted. Once the operator has a clearer view of his difficulties he is better able to attack them.

In answer to Mr. Moore, I wish to point out that the unbalancing of which I am speaking is not momentary but continuous, and is due to the disposition of the bus bars. In a ferro-alloy furnace of low power factor, say around 75 or 80, the operator has to choose between two evils. If he tries to keep his high-tension circuit balanced to please the power company his furnace will be quite unbalanced. If, on the other hand, he tries to balance his load in the furnace by equalizing the power under the three electrodes he unbalances his high-tension circuit. He will therefore have to compromise and if he has several furnaces he can easily connect them in such a way that the disturbance of the power company's line will be kept within satisfactory limits.

B. D. Saklatwalla: In the discussion the matter of uneven balance of the electrodes in a three-phase furnace has been brought out. The conditions of the bath at the electrodes can be kept uniform, avoiding an unbalance, by proper feeding of raw materials. In the case of the ferro-vanadium furnace this is achieved by a continuous feeding of the material between the electrodes at a rate commensurate with the electrical load.

Another point brought out by the discussion is the possibility of the use of the induction furnace in competition with the arc furnace. Besides circulation of the bath and other mechanical, or rather hydro-dynamical, effects, the passage of current through the molten metal may have effects of a molecular or even electronic nature depending on the electro-magnetic forces set up within the fluid metal. A study of such electromagnetic influences may prove some superiority of induction furnaces over that of the arc type, achieving a more perfect refinement of the metal.

A. N. Anderson: Theregulation of the power input in an electric furnace by means of a true watt control offers several advantages over current regulators as there are several factors entering the problem. Some of these factors lie outside of actual furnace operations but are nevertheless worthy of consideration as they form very important factors in the problem as a whole.

The use of a control mechanism in which the current alone is kept constant can not govern or regulate other than the current consumption.

The parties interested in the power consumption of an electric furnace may be divided into three groups:

1. The manufacturer, selling the product of the furnace, who wants maximum production at minimum expense.

2. The operator responsible for the product.

3. The central station furnishing the power and interested in a high power factor, balanced load and freedom from excessive fluctuations.

The control of the energy input is therefore a factor of prime importance.

Because of the prevailing methods of transmitting power a large majority of electric furnaces now in operation are of the three-phase three-electrode type whether used for the smelting of ores or the production and refining of steel.

It is not possible to control and keep constant with any degree of accuracy the effective power input in these furnaces by means of current regulation alone or the combination of current and voltage regulation, where the voltage regulation consists of keeping a balanced potential between the electrodes and furnace charge.

All that a central station can do to deliver reliable power is to guard against overloaded lines and to keep, the voltage constant at the station. It cannot materially regulate the load factor.

On lines supplying power to customers using electric furnaces of various types and of more or less intermittent energy consumption it is very difficult, if not impossible, to keep up a steady voltage and power factor. There are often variations in voltage between phases of the same line and the power factor in phases may also vary.

These conditions are not noticeable where power is supplied to motors or apparatus having balanced circuits, but is noticeable where devices such as electric furnaces are used.

It is highly desirable both from a technical as well as commercial standpoint to be well supplied with measuring instruments to keep a check on the various fluctuating factors.

A properly metered electric furnace installation, employing current regulators, will often show an erratic behavior of the furnace and irregular power consumption in spite of the control indicating a steady amperage flowing, as in addition to the comparatively small fluctuations in the incoming power lines those of the transformer secondary vary to a much greater degree, and it is not at all surprising to find such conditions as Mr. Andreae has investigated.

On the other hand, a furnace installation operating on a true watt control principle automatically corrects fluctuations due to variations in voltage and power factor so that the actual predetermined energy is controlled, measured and delivered to the furnace, and conditions such as Mr. Andreae describes cannot exist.

Assuming that volts times amperes times power factor are the factors that produce the heat and temperature required for the successful operation of an electric furnace of the type under consideration, it is apparent that the control of but one of these is insufficient unless one assumes that the others are constant, which unfortunately is very seldom the case. Often a heat gone wrong, a tap or power "off" on analysis, has been blamed on the operator or laid to some other cause when the real culprits were the current regulators.

To the manufacturer who pays the bill from the control station and collects from his customers for his product, the watt regulator serves to prevent peaks much more efficiently than a current regulator, thereby keeping costs at a minimum; it regulates the actual power input into the furnace and thereby maintains the predetermined energy at which the furnace is set to operate, thus helping to produce the desired product uniformly and at maximum efficiency.

The watt regulator benefits the central station insofar as it has a tendency to more effectively balance the load on the feeder lines and to prevent prolonged duration of peaks.

Discussion at Annual Convention

CABLE CHARGE AND DISCHARGE[1] (Steinmetz) **DIELECTRIC STRENGTH RATIO BETWEEN ALTERNATING AND DIRECT VOLTAGES**[2] (Hayden & Eddy) **CABLE GEOMETRY AND THE CALCULATION OF CURRENT CARRYING CAPACITY**[3] (Simons),
Swampscott, Mass,, June 26, 1923

J. B. Whitehead: The approximate exponential shape of the charge and discharge curves of composite dielectrics has long been recognized, and many efforts have been made to explain the departure of these curves from the pure exponential form, by various assumptions as to the structure of the dielectric in various arrangements of high resistance paths in conjunction with capacities. Several of these suggestions are in approximate conformity to the experimental observations of the charge and discharge curves as observed with continuous potentials. One of the simplest of all is that used by Dr. Steinmetz in which assumption is made of a very high resistance in series with a capacity, a number of such combinations being assumed with different relative values of the resistances and capacities. Another recent analysis of the problem has been given by K. W. Wagner who, with an entirely different method of approach, through a modification of Maxwell's suggestion of a mixture of two or more dielectrics, reaches the same conclusion as does Dr. Steinmetz, namely that the charge and discharge curves have one principal exponential term accompanied by one or more additional terms of relatively much smaller magnitudes.

The behavior of dielectrics under alternating stress is very obscure and presents one of the most important problems now confronting both the physicist and the electrical engineer. None of the theories of dielectric composition as offered by the physicists is sufficient to explain the diverse behavior of ordinary insulation under alternating stress. The general case was investigated by Rowland many years ago and since by a number of others. The results of these studies will in many cases conform qualitatively to some of the main lines of experimental observation. Quantitatively, however, they are quite insufficient to explain the facts, and the anomalies of observation are so numerous as to clearly indicate that our present knowledge is quite insufficient either to explain the facts of observation, or to predict beforehand the behavior of even the simplest types of insulation. Dr. Steinmetz makes a notable contribution to the alternating-current case in reaching the conclusion that the energy component of the charging current corresponds to the initial value of the absorption current under continuous voltage. In doing this he has made certain assumptions which would appear to demand experimental confirmation. It is highly important, however, in that it appears to link up the dielectric phenomena of the continuous and alternating voltage fields.

The real problem of insulation is a knowledge of the ultimate nature of the processes which go on in the structure of dielectrics. What for example is the nature of the conductivity of the high resistance path assumed by Dr. Steinmetz, and how does the capacity in series with this resistance arise? Do they exist independently, or are both properties inherent in the structure of single molecules or atoms? We have gone so far in our studies of the wide variety of commercial insulation as to reach the conviction that it is not possible to design insulation with any certainty that its various properties can be safely predicted. Further attacks must be made through simplified problems directed toward the ultimate processes involved. The Committee on Insulation, Division of Engineering, National Research Council, working in conjunction with the Research Committee of the A. I. E. E., exists primarily for this purpose. The statement of The Problem of Insulation as prepared by these Committees is published in the June number of the Journal A. I. E. E. Considerable attention is given in this published report to the phenomenon of absorption. The Committees bespeak the interest and cooperation of all members of the Institute in attacking these problems by the methods set forth in the report.

J. Slepian: Dr. Steinmetz believes that dielectric absorption of charge is to be explained entirely by the inhomogeneity of the dielectric.

However, since conduction in a dielectric is not as simple as metallic conduction, charges may arise within an entirely homogeneous substance due solely to the passage of current. I can give some very simple examples of this.

Undoubtedly the most homogeneous dielectric imaginable is a perfect vacuum, and thanks to the general interest in radio most of us know something about conduction in a vacuum. We all know that if two electrodes in a high vacuum are sufficiently hot, current may be carried across the space between them. Thus the vacuum dielectric begins to leak when the electrodes are hot enough. It is now well known that the electric gradient across the space is not uniform under these conditions, and that a space charge is produced. Space charge is a very common term now. This space charge is nothing but a charge soaked into the vacuum dielectric. The transient in establishing this space charge is very rapid due to the high velocity with which electrons move in vacuum, but it still is an absorption transient, such as this paper describes for cables. Nevertheless the vacuum is homogeneous.

Passing to the case where we actually have matter, the next case in the order of difficulty would be conduction through a gaseous dielectric. We can make a gaseous space between electrodes conducting by means of an ionizing agent. This might be a source of X-rays acting uniformly on the gaseous space or ultra-violet radiation acting on the electrodes. The distribution of gradient and charge for this kind of conduction is fairly well known. I think Mie was one of the first analysts who worked it out, and you will find his work described in J. J. Thompson's "Conduction in Gases." When current flows across a uniformly ionized air space, the gradient again is not uniform, but again space charges are produced. These space charges may be called soaked in, or absorbed charges, if you like. Again the transient in establishing such charges is of very short duration because the ions in gases also move very rapidly, but the transient exists nevertheless in spite of the homogeneity of the gaseous space.

In solid and liquid insulations the carriers of the current probably move with very slow velocity so that the time in establishing the stored up charges will be relatively very long. I do not happen to know definitely that you do get absorbed charges in strictly homogeneous liquid or solid dielectrics, but I strongly suspect that this is the case.

I do recall that in some respects the conductivity in some homogeneous dielectrics is similar to the conductivity in gases. For example, with the same gradient larger leakage may be obtained with the electrodes far apart than when close together. This shows that dielectrics do not have a simple ohmic resistance, and it seems to me that even in a homogeneous medium space charges or soaked-in charges may be produced, resulting from the nature of conduction in the dielectric.

D. E. Howes: The labor involved in obtaining reliable dielectric strength values for such a large number of conditions is enormous—a fact, which will be concurred in by all who are familiar with insulating materials.

The results in the Hayden and Eddy paper bear out the fact, which the practical engineer should consider an axiom,—that

1. Published in advance copy form only.
2. A. I. E. E. Journal, 1923, Vol. XLII, July, p. 706.
3. A. I. E. E. Journal, 1923, Vol. XLII, May, p. 525.

the most satisfactory test which can be given a commercial machine or material is that which corresponds most nearly to the conditions under which it is expected to be used. Short cuts should be carefully investigated before being adopted, as was wisely done by the writers of this paper. I can take no exception to their experimental procedure or results obtained. Further, I do not intend to attempt to fully explain the reasons for some of their observations. It would be, perhaps, impossible and at any rate hardly worth while. What I do wish to point out is that, from theoretical considerations alone, it is fundamentally wrong to expect any very simple or reliable dielectric strength ratio as defined by the authors of this paper, at least for practical insulating materials.

Let us borrow again Maxwell's conception (*El. & Mag.*, Vol. 1, page 453) of a composite dielectric, a conception which has proven so valuable and so actually real.

Consider two adjacent elements or strata of dielectric in series, located any place you please in a composite dielectric, whose specific inductance capacities, specific resistances are respectively denoted by K_1, K_2 and ρ_1, ρ_2.

Suppose a direct voltage be applied to the outer surfaces. It will divide between the two dielectrics so that the potential gradients will be in the ratio of ρ_1 and ρ_2. If, however, the voltage is changing rapidly, either pulsating or alternating, the voltage gradients in medium 1 and 2 will be in the ratio of K_2/K_1.

Suppose $\rho_1/\rho_2 = 1$, $K_1/K_2 = 2/4$. Then for direct voltages the gradients in the two media would be equal. For a rapidly changing voltage, the gradients in 1 and 2 would be in the ratio of 2/1 and we would expect medium *I* to fail prematurely, so that in this case the maximum value of the alternating voltage breakdown might be less than for direct voltage, unless of course, it had a much greater dielectric strength. Thus, the distribution of stress may be widely different, even though the total voltage applied be the same. With a different stress distribution throughout the insulating material, we would expect the dielectric strength to be different. Only the most homogeneous material could be expected to have a dielectric strength ratio of unity. It would be reasonable to expect that it would not vary widely for a uniform grade of material subjected to a uniform test. For this reason, direct voltage may have a limited application where its significance, relative to alternating voltage test values, has been predetermined.

It is evident that ρ_1 and ρ_2 will not vary with temperature according to the same law. Continuing, with reference to the above conception and its extension by Maxwell to account for absorption or residual charge, it is obvious that if the rate of change of voltage be very slow in comparison with commercial frequencies the relative potential gradients in different component parts of the dielectric may be determined partly by the specific resistances of those components. In other words, let us ask this question,—What is the rate of change of potential that determines whether the relative gradients shall be according to K_2/K_1, or as ρ_1/ρ_2? Is there a sharp dividing line?

In view of the well known phenomenon that a condenser exhibiting absorption does not become fully charged for quite an appreciable time, it seems reasonable to expect that there is no sharp dividing line, but that both factors contribute, and the relative importance of each will depend upon the rate of change of voltage. When the rate is very slow, the specific resistances of the component media are dominant in effect while, when the rate is rapid, the specific inductive capacities control. Thus, it is evident that the dielectric strength ratio has little meaning unless we specify very closely the rate of application of voltage.

When we consider the fact that nearly all practical solid insulating materials are composite, and analyze how they should behave under different types of fields, we must realize how little real additional information concerning dielectric behavior this so-called dielectric strength ratio actually tells us. It is realized that, on the whole, the phenomena are not as simple as explained, but I believe that in general the theoretical considerations are very well born out by the experimental data given in the authors' paper. For obvious reasons, then, I do not think that direct voltage should be employed for testing insulating materials which in service are to be subjected to alternating potentials, where the dielectric strength is to be determined. Direct voltages lower than this, however, should be useful in routine cable testing to indicate any gradual changes in their quality.

I am of the opinion that we should not draw any new conclusions as to the ultimate nature of a dielectric breakdown from the consideration of this paper. Aside from known effects of temperature etc. I believe insulation failure is dependent upon the maximum voltage attained for an appreciable length of time, regardless of its form. The ultimate cause of breakdown is doubtless, cumulative ionization, although this itself is influenced by numerous other factors.

In conclusion, I wish to express the opinion that the real nature of the mechanism of dielectric failure will not be found by any commercial or practical engineering tests that we may devise but by indirect methods. By this I mean that we should study it from a purely scientific viewpoint to determine the location and behavior of an electron in it.

D. M. Simons: I have just come across a recently published article which bears so directly upon the papers by Dr. Steinmetz and Messrs. Hayden and Eddy that I thought it might be interesting to mention it briefly, particularly one test that was made. I am referring to an article by Grünewald entitled "The Breakdown Strength of Solid, Laminate Insulating Materials with Various Types of Electrical Stress," (*Archiv fur Elektrotechnik*, 1923, Vol. XII, p. 79). Grünewald performed breakdown tests on insulation not only with alternating and continuous voltages but with various types of impulse. He did not show the effects of different rates of applying the voltage, or of different temperatures, but his work is of interest on account of the variety of impulses impressed on the insulation. His tests were mostly upon mica, and unfortunately no tests were made upon impregnated paper. Grünewald includes also a mathematical section, and while he does not obtain a solution for n-layers, he obtains an equation for the voltage distribution across two layers of insulation as a function of time, and it is interesting to note that this equation (**13**) can be transformed to agree with Steinmetz's equation (**18**).

Before proceeding to describe what I believe is the most interesting test made by Grünewald, I would like to ask if any breakdown tests have been made upon a dielectric which already contains residual charges. We might consider the case of a dielectric which has widely different breakdowns for slowly applied and rapidly applied voltages. Dr. Steinmetz has very clearly explained that the difference in breakdown strength is due to the fact that for the rapidly applied voltage the voltage distribution is determined by the relative permittivities of the layers, while for the slowly applied voltage the resistivity is the determining factor. My particular thought is what would happen if a continuous voltage close to but below the breakdown voltage was impressed on this dielectric until the residual charges had completely soaked in, and a rapidly applied voltage was then impressed on the dielectric. It seems to me that in this case the voltage distribution would be determined by the internal charges and would be according to resistivity, and the ratio of d-c. to a-c. breakdown would be reduced to or toward unity.

Grünewald did not perform this test, but he did the opposite. That is, he performed breakdown tests on condensers which had previously been charged in a direction opposite to the final test voltage, and he found that this had a very great effect in lowering the breakdown strength. As far as I can determine he broke down the previously charged condensers with single steep-front impulses only, and found that in general for this type of surge, the breakdown value was about *halved* if the condenser was previously charged in the opposite direction.

It seems that breakdown tests on dielectrics which have previously been charged in either direction may throw additional light on the fundamentals of the behavior of solid dielectrics.

Herman Halperin: In his opening remarks, Dr. Steinmetz made some comments about the relative slow progress that has been made in the art of insulation. I think these papers are a definite step in the progress that seems to be needed. The first two papers deal with stresses and the last with heat conduction through complicated structures of conductors and insulations such as multi-conductor cables.

In Dr. Steinmetz' paper he refers to the decrease in the internal transient current and gives an example which indicates a ratio of about 20 to 1. In some tests made in Chicago on long underground lines, we find that the final current was as small as 1/150th or 1/200th of its initial value. If we tried to find the equation for this decrease of current against time by using an equation with one transient, we would obtain a curve which would hold only for the data taken for one minute or so; and it was during the first minute of the test that the decrease in current was very rapid. Perhaps it would be necessary to use another transient term, as Dr. Steinmetz points out, in order to equate the entire curve.

In connection with the d-c. a-c. ratio, after we do find just what is exactly the ratio for one kind of electrical apparatus, for instance, underground cable, it would still seem necessary to discover it for joints connected with the cable. This further complicates the situation because we might secure a dielectric strength ratio of 1.78 for one cable and probably something different for the joints; and in making a test the whole line has to be subjected to the voltage at one time.

In Mr. Simons' paper, he has, I think, done a great deal in showing how accurately the thermal resistivity of a complicated arrangement of conductors and insulation can be determined. In the appendix, he shows that his more correct method would indicate an error of about 20 per cent in some results which were published by a research committee in England; so these accurate methods greatly help correlate the various researches.

Mr. Simons deals mostly with the determination of the geometric factor. But, of course, for the installed cable in this country, there are other very important factors in heat dissipation such as H, the thermal resistance of the earth per foot of duct, and the resistance of duct structure itself. While there may be variations for the thermal resistivity of insulations of as much as about 50 per cent, the heat dissipating ability of the duct structure and surrounding soil may vary several hundred per cent. A large percentage of the total drop from copper to the base soil temperature is through the soil and duct structure and there is a great deal of work to be done in this field.

H. B. Dwight: Mr. Simons has made a distinct advance in the calculation of the geometric factor of multi-conductor cables and has produced by his graphical method more accurate results than were available before. The publication of this graphical method, however, brings up at once the question whether a direct and accurate mathematical calculation cannot be made. This would be especially desirable in the present case, for the graphical method, besides having the errors of measurement inherent in any graphical method, has the theoretical approximation in that the flow lines are not those pertaining to true circles, a fact which is pointed out in the paper.

A graphical method was justified because the formulas which had been published for multi-conductor cables were all approximate, since they assumed that the electric charge on each conductor was equivalent to a charge concentrated at a point of the section of the cable. This, however, gives rise to equipotential surfaces which are not circular, and so cannot coincide with the surfaces of the round wires or cables.

It appears that practically all formulas for capacitance have been based on charges concentrated at points, or uniformly distributed along lines or over surfaces. This is true, at any rate, of the published formulas for multi-conductor cables. Clark Maxwell states in Chapter 7 of his book on Electricity and Magnetism published in 1873 that every electrical problem of which we know the solution has been constructed by the inverse process of finding the shape of the conductors from the potential due to assumed charges of electricity. He also states that the only method by which one can expect to solve a new problem is by reducing it to one of the cases in which a similar problem has been constructed by the inverse process. Maxwell's statement has been quoted in fairly recent articles, and the limitation which he gives that the inverse process must always be used and that one cannot start with an assumed shape of conductor seems to hold in the most recent calculations of capacitance. A general method which would correctly use the direct process of starting with given shapes of conductors would therefore be very useful.

I wish to present an accurate method using the direct process of calculation of capacitance and geometric factor of multi-conductor cables. This method consists in first assuming a uniform charge on the surfaces of the round conductors and their images. From this the resulting charge at any point of the conductors can be calculated. This may be called the first additional charge, and it is in the form of a Fourier series, that is, a series involving cos A, cos 2 A, cos 3 A, etc. The cosines often disappear when integrated around the circle. The second additional charge can now be calculated, resulting from the first additional charge, and so on, until the terms become small.

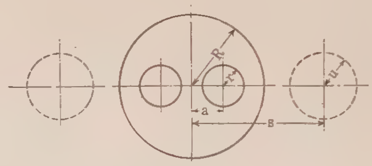

FIG. 1

This method has been used to determine the capacitance of a single-phase overhead line, and the result for a given example agreed with the result by the standard hyperbolic cosine formula to six significant figures. The formula for a two-conductor cable is given herewith. That for a three-conductor cable is longer.

Capacitance of two-conductor cable

$$= \frac{1}{2 \operatorname{logh} F_c}$$

$$2 \operatorname{logh} F_c$$

$$= \operatorname{logh} \frac{(s-a-u)\,(s-a-r)\,(s+a-u)\,(s+a+r)}{r\,u\,(2\,a+r)\,(2\,s-u)}$$

$$+ \sum_{n=1}^{n=\infty} \frac{L_n}{n} \left[1 - \left(\frac{r}{s-a-u} \right)^n - \left(\frac{-r}{s+a-u} \right)^n + \left(\frac{-r}{2\,a+r} \right)^n \right]$$

$$- \sum_{n=1}^{n=\infty} \frac{M_n}{n} \left[1 - \left(\frac{u}{s-a-r} \right)^n - \left(\frac{u}{s+a+r} \right)^n + \left(\frac{u}{2\,s-u} \right)^n \right]$$

$$u = \frac{R^2\,r}{a^2 - r^2} \qquad s = \frac{R^2\,a}{a^2 - r^2}$$

$$A_n = \left(\frac{r}{s-a} \right)^n - \left(\frac{-r}{2\,a} \right)^n + \left(\frac{-r}{s+a} \right)^n$$

$$F_n = -\left(\frac{u}{s-a}\right)^n + \left(\frac{u}{2s}\right)^n - \left(\frac{u}{s+a}\right)^n$$

$$B_n = -\left(\frac{r}{s-a}\right)^n \sum_{k=1}^{k=\infty} \frac{\lfloor n+k-1}{\lfloor n-1 \lfloor k}\left(\frac{u}{s-a}\right)^k F_K$$

$$-\left(\frac{-r}{2a}\right)^n \sum_{k=1}^{k=\infty} \frac{\lfloor n+k-1}{\lfloor n-1 \lfloor k}\left(\frac{-r}{2a}\right)^k A_K$$

$$-\left(\frac{-r}{s+a}\right)^n \sum_{k=1}^{k=\infty} \frac{\lfloor n+k-1}{\lfloor n-1 \lfloor k}\left(\frac{u}{s+a}\right)^k F_K$$

$$G_n = -\left(\frac{u}{s-a}\right)^n \sum_{k=1}^{k=\infty} \frac{\lfloor n+k-1}{\lfloor n-1 \lfloor k}\left(\frac{r}{s-a}\right)^k A_K$$

$$-\left(\frac{u}{2s}\right)^n \sum_{k=1}^{k=\infty} \frac{\lfloor n+k-1}{\lfloor n-1 \lfloor k}\left(\frac{u}{2s}\right)^k F_K$$

$$-\left(\frac{u}{s+a}\right)^n \sum_{k=1}^{k=\infty} \frac{\lfloor n+k-1}{\lfloor n-1 \lfloor k}\left(\frac{-r}{s+a}\right)^k A_K$$

For C_n and H_n use the same formulas as for B_n and G_n except change A to B and F to G.

For D_n and I_n change B to C and G to H, etc.

$$L_n = A_n + B_n + C_n + \ldots$$
$$M_n = F_n + G_n + H_n + \ldots$$

It is to be noted that the terms involve only the dimensions of the cable. The terms can be calculated with a slide rule. As there is a considerable number of these terms, the method cannot be said to be a short one.

The formula for a two-conductor cable has been used to check one of the values of geometric factor in Mr. Simons' paper within less than one per cent. For $t/T = 1$ and $\frac{T+t}{d} = 1$ the formula gives 1.730 to compare with 1.718 given by the graphical method.

R. Notvest: In connection with the Hayden-Eddy paper, it was very interesting to note the behavior of composite dielectrics under high direct as well as alternating-current potential stresses. The authors investigated practically all important commerical insulation materials from mica, oil, glass to paper and I regret that they have not extended the scope of their investigations upon slate, for slate, a composite dielectric of great commercial importance, is the classical example of the variation of the dielectric strength ratio of a given material between direct and alternating-current potentials. Slate has a rather high insulation value for direct current, but may show considerable leakage under alternating current of such low potentials as from 1500 volts up.

I have made a number of tests which plainly showed that as far as slate is concerned, leakage under high a-c. potentials cannot be ascribed to ionization of the dielectric, but is distinctly an impedance or condenser effect. This is due to the fact that slate contains among other ingredients also around 4 per cent of metallic oxides such as ferric and ferrous oxide as well as pyrites which to all practical purposes are distributed uniformly in almost molecular form throughout the otherwise electrically inert substances. Each such particle of metallic oxide is capable of assuming a definite capacity charge under alternating potentials and is interconnected with the others through an ohmic resistance of relatively high value, the 0.2 to 0.5 per cent of carbonaceous matter which slate contains. Impedance leakages actually measured on a number of various samples which were afterwards chemically analyzed, showed that variations of the metallic oxide content, that is, the capacity effect or the ohmic resistance, that is, the content of carbonaceous substances in graphitic form, corresponded very closely to estimated results based on Dr. Steinmetz formulas of a condition of a circuit having capacities and ohmic resistances in series. I am convinced that additional research on slate would produce valuable data and would give an insight of the stress distribution in composite dielectrics and the very pertinent problem of insulation in general.

Mr. Davis: Mr. Simons' paper and the formulas contained therein will undoubtedly be of inestimable value to engineers in calculating current capacities. His errors of twenty per cent of the approximate formula (I think he said twenty) and the errors published in the JOURNAL of the Institute of Electrical Engineers can hardly be considered serious when we think of the possible errors we have in the thermal resistance of this material.

I merely wanted to call attention to the fact that thermal resistivity as published by the Institute showed variations of approximately from 350 to 1250 watts per centimeter cube, per degree centigrade. Tests that we have made but not completed showed variations running from 300 watts per centimeter cube per degree centigrade to 1800. In other words, we have a variation there of about six hundred per cent. Now, the application of any of these formulas for calculation of temperature rises depends absolutely upon the use of some of those constants which really have wide variance. Consequently it gives an error of twenty per cent. That is small when the amount of thermal resistance varied about six hundred per cent.

C. F. Hanson: Referring to Table I of the paper by Hayden and Eddy the data given for impregnated cable paper are very interesting, particularly the data given for a rate of voltage rise of 5 per cent per second. The dielectric strength ratio of one paper at 25 deg. cent. is 1.343 when the rate of voltage rise is 5 per cent per second whereas the ratio of one paper at the same temperature is 2.470 when the rate of voltage rise is 20 per cent per second. One ratio is twice the other. This difference indicates that a cable of good dielectric qualities might be damaged when it is tested with direct voltage if the voltage is applied too slowly.

These data may also be interpreted in another way. The alternating breakdown voltage at 25 deg. cent. for 2 papers is 18.2 kv. when the rate of voltage rise is 5 per cent per second whereas the breakdown voltage is only 6.6 kv. when the rate of voltage rise is 20 per cent per second. The difference in breakdown voltage is about 300 per cent which is more than can be attributed to the difference in the rate of application of voltage judging by other data presented. The paper used in the former case, had a higher dielectric strength than that used in the latter case as determined from alternating voltage tests. It is then interesting to note that the dielectric strength ratio of the high dielectric strength impregnated paper is only one-half of that of low dielectric strength impregnated paper. In other words, if two cables were tested at the factory with alternating voltage and one was found to have 50 per cent higher dielectric strength than the other, and if these two cables were subsequently tested with direct voltage after installation in the field, the cable of lower dielectric strength would pass whereas the one of higher dielectric strength might fail. As cables are operated on alternating voltage, it would seem that the direct-voltage test had passed a poor cable and had eliminated a good one.

The authors state that they obtained an average value of 1.773 for the dielectric strength ratio which corresponds to 2.501 as the ratio between direct voltage and the root-mean-square alternating voltage. It must be borne in mind that this value was obtained on a comparatively thin insulation. The thickest insulation used was four layers each 0.2 mm. thick or a total thickness of about 2/64ths inch. In high-voltage cables a thickness of 40/64ths inch is used. The dielectric strength ratio would be considerably less than 1.773 for a thickness of 40/64ths inch as indicated by the author's data. Furthermore, the dielectric strength ratio obtained here is for momentary application of voltage. It may be different for a prolonged application of voltage. In testing cables the voltage is generally applied for 5 minutes. It would, therefore, be of

practical interest to know what the ratio is when the time of application of voltage is 5 minutes.

Harvey L. Curtis: The paper by Dr. Steinmetz can for convenience be considered in two parts, first, the mathematical, and second, the experimental. It seems unfortunate to me that Dr. Steinmetz does not refer to the earlier mathematical work on this subject of a stratified dielectric.[1] His discussion of the energy storage in a stratified dielectric is, I think, new. However, I am not as yet willing to accept the definition of "apparent" or "effective" capacitance which is brought out as a corollary to this discussion.

It seems to me that Dr. Steinmetz overlooked at least one interesting conclusion that can be drawn from his equations. From equation (**36**) it is evident that the tangent of the phase difference (90 deg. minus the phase angle) is C_2/C_1. Substituting the values given in equations (**38**) and (**39**), it follows that as a first approximation, the phase difference is inversely proportional to the frequency.

In the paper above referred to, I derived an equivalent equation and called attention to the fact that this conclusion did not agree with the experimental data then available on condensers. I have hoped to see this test applied to a composite structure, such as a cable, as I believe that this will tell whether or not the theory of a stratified dielectric is of practical importance.

In the experimental part of his paper, Dr. Steinmetz measures the current which flows into a cable when a constant voltage is impressed on the cable terminals. The current which flows after the first charging current he calls "slow transient" or "internal transient." He then computes the constants in an exponential equation of two terms so as to make the observed and computed curve agree at five points. When he has done this, he finds that the theoretical and experimental curves agree within experimental error. Since the theory of a stratified dielectric shows that under certain conditions such an equation will result, he concludes that the observed phenomena are explained by this theory. However, he fails to connect the constants in this exponential equation with the dielectric constant and resistivity of the materials of the cable, which the mathematical part of the paper has shown should be possible.

Everyone who has investigated the subject agrees that there is an "internal transient" due to the stratification of a dielectric. However, there is considerable question whether, in any electrical structure, the "internal transient" which is caused by the stratification of the dielectric is an appreciable part of that which is observed. I regret that Dr. Steinmetz has not shown some experimental method by which this question can be settled.

R. J. Wiseman: The paper by Messrs. Hayden and Eddy is of great value to all who have occasion to test electrical insulation on direct and alternating voltage. With the introduction of high potential direct voltage testing the question naturally arose as to what value of voltage should be used. Should we take a value equal to the root-mean-square of the alternating voltage or the maximum value of the alternating voltage? We know that when testing with alternating voltages, insulation is subject to the maximum voltage and therefore if it is able to withstand this voltage, the insulation should be capable of withstanding a direct voltage of equal value. Instead of taking a value of direct voltage equal to the maximum value of alternating voltage, we find that a value of 2.5 times the root-mean-square alternating voltage which is 1.773 times the maximum value, has been taken as an arbitrary one in view of tests made abroad on cables. After giving due credit to the work done abroad as to what value of direct voltage in proportion to alternating voltage is necessary to cause breakdown of insulation, the question arises, do we want to make time tests on insulation using direct voltages 2.5 times r. m. s. alternating voltage or a dielectric strength ratio of 1.773.

I do not believe we do. The paper by Messrs. Hayden and Eddy brings out some very valuable information as to the comparison of direct and alternating voltage breakdowns of insulation under varying conditions. Their Table I shows interesting data which should cause us to defer deciding definitely on the factors to use in determining the value of direct voltages in proportion to alternating voltages. Different insulations give different values of dielectric strength ratio and for the same insulation this ratio changes with temperature, thickness and rate of voltage rise; three important quantities when testing. In all cases but impregnated paper the dielectric strength ratio is much less than 1.773 and in many cases even less than one, which means puncturing voltage on direct potentials is less than on alternating potentials. It would be unfair to test such a material at a direct voltage of 1.773 times maximum value of alternating voltage.

Consider the influence of thickness on the ratio. Take dry cable paper, four layers, 20 per cent per second voltage rise, the ratio is 1.790 and for 32 layers 1.085, a drop of 39.4 per cent in terms of 1.790 for a change in wall thickness from 0.8 mm. (31.4 mils) 6.4 mm. (252 mils). As we test thicknesses greater than 6.4 mm. (252 mils) it appears we may get ratios less than one for the greater thicknesses and again 1.773 is unfair.

Referring to the rate of voltage rise, we note that a rate of increase of 0.1 per cent per second gives the lowest values for the dielectric strength ratio. This rate is equivalent to taking 16.7 minutes to bring the voltage up to cause breakdown. This is a slow rise and is almost comparable to a constant voltage test. Some of the values of the ratio for dry cable paper are slightly above but the average of all values shown give a value below 1.

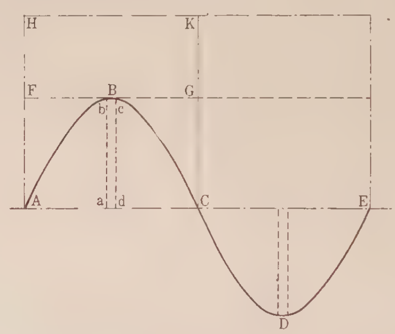

Fig. 2

When we study the results obtained for impregnated cable paper we find values of ratio above and below 1.773 not consistent, the range being from 2.775 to 1.238. In view of the wide range in value of ratio it doesn't seem possible we have a right to average all values and take this average as representing the ratio for impregnated cable paper because it is the average of several variables for which the ratio itself is quite a variable.

Tables II and III also show that the ratio is different for each kind of insulation and departs considerably from 1.773.

As the paper shows that in the data reported the ratio of direct voltage breakdown to maximum value of alternating voltage breakdown is different for each kind of insulation, we should not establish a general value of direct voltage in terms of alternating voltage for insulation testing but give a value of each type of insulation.

Aside from considering that in some cases much greater value of direct voltage than alternating voltage is necessary to cause breakdown on constantly rising voltage, let us consider the effect of the long time application of the high direct voltage on the possibility of weakening the insulation.

Referring to the fig. 2, $A\ B\ C\ D\ E$ is one cycle of an alter-

1. Maxwell: *Electricity & Magnetism*, par. 328.
Rowland: *American Journal Science* (4) 4. p. 29; 1897.
Curtis: *Bull. Bureau of Standards* 6; p. 468, 1910. S. P. 137.
Grover: *Bull. Bureau of Standards* 7; p. 519; 1911. S. P. 161

nating voltage sine wave. Let us assume that the insulation is under effective electric stress, for one fortieth of the time each side of the maximum, that is we will consider the insulation as being stressed for test purposes as soon as the voltage reaches the instantaneous value corresponding to 99.7 per cent of the maximum value and lasts until the voltage again reaches this value when decreasing. This is shown by the curve $b\ B\ c$. The line $F\ B\ G$ represents a direct voltage equal to the maximum value of alternating voltage. The line $H\ K$ represents a direct voltage 1.773 times as great as the maximum value of direct voltage. The area $a\ b\ c\ d$ represents the product of alternating voltage and time of application and may be taken as a measure of the stress under alternating voltage. Likewise the areas $A\ F\ G\ C$ and $A\ H\ K\ C$ represent the product of direct voltage and time of application for the respective voltages.

These areas are a measure of the relative stresses which the insulation is subject to. Although we cannot say, two equal areas, one having twice the voltage of the other, give the same effective stress, still on a time basis for the sake of discussion we can say the net effect is the same. Taking this viewpoint and calling the area $a\ b\ c\ d$ unity, then the area $A\ F\ G\ C$ is 12.73 and the area $A\ H\ K\ C$ is 22.6. This means the voltage time stress is 12.73 times greater for a direct voltage equal to the maximum value of alternating voltage and 22.6 times as great for a direct voltage 1.773 times the maximum value of alternating voltage. Referring to the results which have been obtained by Messrs. Hayden and Eddy this may be a serious problem for some kinds of insulation and result in weakening of the insulation.

Another source of possible weakening of the insulation is the value of dielectric stress resulting from the high direct voltage test. The stress equivalent to the maximum value of alternating voltage is not great enough to permanently weaken the insulation without chance of recovery. It may so happen that the stress equivalent to the direct voltage will be sufficiently great to permanently damage the insulation, yet not cause it to breakdown and the usefulness of the insulation greatly lowered as a result. If a lower value of voltage had been used, possible sources of weakness would have been found, and yet the insulation have a high factor of safety.

I am a believer in direct voltage testing of insulation and look forward to the time when manufacturers and users of insulating materials will consider it as the routine method of test. However, today this method of test is purely in the formative stage and all the above questions should be seriously considered before we attempt to establish standards for the testing of insulation with direct voltages.

W. N. Eddy: Mr. Hanson brings out two points on which we would like to comment. He thinks that the increase of ratio caused in one case by increased rate of voltage application, indicates that a cable of good dielectric qualities might be damaged by the application of direct voltage at too slow a rate. We feel that such a change of the ratio rather indicates that the ratio of an insulation should not be specified without including the rate of voltage application. In fact, one of the principal points we tried to bring out in the paper was that a d-c.—a-c. ratio is meaningless unless accompanied by such factors as the rate of voltage application, the temperature, the type and shape of the insulation, etc.

He also attempts to draw definite conclusions from a comparison of two breakdown voltages and two ratios. In view of the well known difficulty of obtaining consistent breakdown data on insulation, we believe that such a practise should be avoided, and that in analyzing a collection of breakdown tests, the various values should be considered together, weighed against each other, and only general tendencies noted.

D. M. Simons: I am particularly gratified if I have been in any way instrumental in inducing Mr. Dwight to develop his formulas for the geometric factors of multi-conductor cables. When his formula for the geometric factor of three-conductor cables is available, this phase of cable engineering will apparently have received its final answer.

Several very interesting papers on the subject of the carrying capacity of cables have been published abroad at about the same time as the present paper. The Second Report on the Research on the Heating of Buried Cables[1] is an exceedingly important contribution to our knowledge of most phases of this subject. It is noted incidentally that the errors in the calculation of thermal resistivities in the first Report mentioned in Appendix C have been corrected. It is also very interesting to see that the geometric relationships of three-conductor cables were investigated both experimentally and by a graphical method. The graphical method, which is entirely different from the present one, checks my values about as closely as can be determined from the large scale graph on which the English data is plotted.

Another interesting contribution is "The Heating of Paper-Insulated Power Cables" by Sacchetto[2]. I believe that there should be some word to express the form factor or geometric modulus to take care of the dimensions of the cable in numerical calculations. I have suggested the term "geometric factor" for this purpose. I was not entirely sure that this was the best term, although it seemed sufficiently appropriate and was certainly more concise than some expressions that have been used, such as "number equal to the capacity if the S. I. C. were unity," etc. Sacchetto confirms my choice by calling a similar term a *fattore geometrico.* His geometric factor is $2/n$ times the writer's. Sacchetto also mentions the fact that Picou[3] called a corresponding factor in cable formulas the *facteur geometrique.*

I am very glad that Mr. Halperin has emphasized the possibility of errors due to the duct rise in calculating the allowable current. There is undoubtedly a great deal to be done on this section of the thermal path before we can accurately calculate in advance the temperature rise of cables.

SOME ENGINEERING FEATURES OF THE WEYMOUTH STATION OF THE EDISON ELECTRIC ILLUMINATING CO. OF BOSTON*

(Moultrop and Pope), Swampscott, Mass., June 27, 1923.

S. Z. Ferranti: It seems to me that when once the commercial practicability of such high pressures as it is proposed to use have been successfully demonstrated that you can then take full advantage of this provided you can go in for a very complete system of progressive feed heating (bleeding at a large number of points). As you already know, great economy results from carrying out this process very thoroughly up to the fullest practical limits. On the other hand, it is not possible to do this unless you heat the water from cold up to nearly the temperature of evaporation under working pressure, by bleeding. This in its turn necessitates a boiler which will work efficiently with very hot feed, and this can only be done by air heating to a sufficiently high temperature, I am sure you have considered this all very fully, and I should greatly appreciate your further views on the subject.

There is another point with regard to the details of your installation, and this is the necessity of taking steam backwards and forwards between the turbines and the superheaters. In my installation, made over ten years ago, with a 3000-kw. turbine, with an initial temperature of 750 deg. fahr. and re-superheating to 750 deg. fahr. I followed the same system, but the construction was so arranged that the distance between

1. Permissible Current Loading of British Standard Impregnated Paper-Insulated Electric Cables. Second Report on the Research on the Heating of Buried Cables, Journal of the Institution of Electrical Engineers, 1923, vol. 61, p. 517.

2. l'Elettrotecnica, 1923, p. 181.

3. Revue Générale de l'Electricité, 1917, vol. 1, p. 410.

*A. I. E. E. Journal, 1923, Vol. XLII, August, p. 799.

the superheaters and the turbine was very small. I then came to the conclusion that to make the installation really satisfactory, one should have the re-superheater or re-superheaters closely adjoining the turbine. In those days this would have necessitated firing by gas or by oil, but now possibly you could do this by coal-dust firing, and so get the superheater elements in close proximity to the turbine.

D. S. Jacobus: High-pressure boilers are not new. One hundred years ago Perkins experimented with the use of high-pressure steam. His steam generating apparatus of 1824 consisted of a water heating element or an economizer from which a certain quantity of water heated to 700 or 800 deg. fahr. was discharged at each stroke of the engine, escaping through a throttling device into more highly heated tubes, where it was superheated to 1000 deg. fahr. total temperature, and from which it passed to a steam receiver maintained at the pressure desired for driving the engine. Heating the water to 700 or 800 deg. fahr. would involve operating at the critical pressure of, say, 3000 lb. per sq. in. That there are instances of the sort and that some smaller boilers have been used at high pressure does not detract from the magnitude of undertaking to adapt such high pressures to power plant use.

The performance figures given by the curves indicate how little advantage there is in using a higher pressure than 350 to 400 lb. per sq. in. unless interstage heating of the steam is resorted to. Again, if the experiment of operating a high pressure steam turbine with an initial steam pressure of 1000 or 1200 lb. per sq. in. proves to be successful, 350 lb. pressure or thereabout appears to be about as high as could be employed to advantage by the main steam turbine. Possibly 1000 or 1200 lb. may not result in a plant as successful from a commercial viewpoint as one operated at, say, 600 or 700 lb. absolute pressure with a high pressure steam turbine exhausting into the main steam turbine, in which case the pressure at the main steam turbine for securing the best results would be lower than 350 lb.

Interstage heating necessarily involves additional complication and the added expense and possible difficulties in operation due to the additional complication have an important bearing on the design of the plant. Were there some more ready means of reheating the steam than passing it back to the boiler room through large pipe connections, which for a large size unit must be 20 or 24 in. in diameter for the pressures at which steam is returned to the reheaters, and which would have to be of an even larger diameter should the steam be reheated at some lower pressure, the problem would not be so difficult. Even in the case of a turbine operated at 350 lb. pressure with an initial temperature of 700 deg. fahr. there is a considerable amount of condensation in the lower stages and if there were some practical means of eliminating this condensation it would result in a higher efficiency. All these features should bring out a most interesting discussion.

Another interesting point brought out in the paper is the heating of the feed water by means of steam extracted from the turbine stages, which in this particular case leads to the best over-all plant efficiency through heating the feed water to between 210 and 220 deg. fahr. In the computations the consequent falling off in the heat absorption of the economizer and the resultant excess in the temperature of the gases is taken into account. The addition of an air heater would offset any increase in temperature of the flue gases due to the heating of the feed water, so that with an air heater the most economical temperature for heating the feed water would be higher than without an air heater, for that matter, the entire economizer might be omitted and a large air heater used instead, as is done abroad at the North Tees Station. There are so many angles to the problem that it is hard to say what plan will be adopted in the future in the effort to secure higher and higher efficiencies.

In the case of the boiler for 1200 lb. working pressure a great number of arrangements were considered. In a high pressure boiler of the sort it might seem desirable to use smaller tubes than those selected, which were 2 in. in diameter. Most careful consideration was given to this feature, as well as to the general design of the boiler.

Between seven and eight years ago The Babcock & Wilcox Co. started to make experiments to determine the possibilities of operating a combined boiler, economizer and superheater without the use of a steam and water drum, the arrangement being designated as a series boiler. It was found to be entirely practicable to operate without a steam and water drum, but this involved the use of a feed pump having 100 per cent reliability as a shut down would throw a plant having such boilers out of commission. Experiments were afterwards made on a combination of a series boiler with a regular boiler element having a steam and water drum with the water carried at a given level in the drum in the ordinary way. The experiments were made on a boiler with 2 in. tubes operated at 600 lb. pressure connected to an economizer with 1 in. tubes, the gases flowing upwardly over the boiler and downwardly over the economizer and superheater. The surface of the economizer was about 3.7 times the heating surface of the boiler exposed to the gases, and the economizer steamed continuously throughout the tests. The unit was arranged so that there was a local circulation throughout the boiler and economizer during the starting up period and a forced circulation during the running period. The boiler was a comparatively small one, having 187 sq. ft. of tube surface in the boiler exposed to the gases, 51 sq. ft. of superheater surface, and 685 sq. ft. of economizer surface, or 923 sq. ft. of heating surface in all, and was fired with fuel oil with mechanical atomizing burners. Tests were made with the boiler generating as high as 424 horse power as an average, the unit being run at times at over 500 per cent of rating, based on the total surface of the boiler and economizer and all parts were found to operate in an entirely satisfactory way. The percentage of rating at which the boiler part of the apparatus was driven in the high capacity tests was about 1500 per cent.

In developing the boiler for 1200 lb. working pressure we had before us the results secured with the use of 1 in. tubes in a great number of our marine boilers built for torpedo boat service and the results of the experiments above referred to. We further had before us the results secured with a drumless B & W boiler that we built for test purposes a number of years ago where there was water storage, the drum being replaced by a number of horizontal tubes connected to headers. A great number of different arrangements were laid out and considered and of all of these the one finally adopted was that described in the paper, approached very closely to a standard B & W boiler.

A power plant boiler under the present conditions of service must be arranged so that it can be thoroughly cleaned both inside and out. The use of 2 in. tubes, such as will be supplied for the boiler gives a convenient size for internal cleaning, whereas it is difficult, if not impossible to properly clean tubes, say, 1 in. in diameter and smaller. Were it possible to maintain at all times absolutely tight surface condensers, it would then be unnecessary to clean the interior of the boiler tubes and the art of boiler design would be considerably simplified and smaller diameter tubes could be used provided they were arranged so that they could be thoroughly cleaned on the outside. For years The Babcock & Wilcox Co. believed that it was ready to put out a B & W boiler for any desired pressure for power plant service through using the Marine B & W boiler, in fact, the test boiler of drumless construction that has been referred to was built with 2 in. tubes for a pressure of 750 lb. per sq. in. The difficulties that were experienced at some plants in maintaining the outer surface of boiler tubes clean from slag and soot when run at high ratings convinced operators of power plants that it would be a mistake to install the 2 in. tubes in groups of four as in our marine boilers, because with the tubes so arranged there are no diagonal lanes available between the tubes for cleaning the outer surface of the tubes. A new forged steel header was

therefore designed and constructed where the tubes are staggered and arranged with horizontal and diagonal lanes between all of the tubes, thereby making it possible to clean the outer surfaces of the tubes through the diagonal lanes from above and below the tubes. All B & W boilers for the higher pressures are now fitted with this new form of header. The case is different from marine boilers, which have a relatively narrow width and where all of the tubes may be cleaned on the outside by opening the side casing doors, and brushing the tubes through the horizontal lanes between the rows of tubes, which would be an impractical method for the wider boilers and settings used for power plant work.

Attention is called in the paper to the use of the forged steel drum of seamless construction for the 1200 lb. boiler and to the bending of the ends of the horizontal circulating tubes which enter the drum so that they enter at circumferential lines which are twice as far apart as the distance between the horizontal circulating tubes where they enter the headers, thereby greatly increasing the efficiency of the ligaments between the tube holes. There are two circulating tubes running from the top of each uptake header to the steam and water drum and the ends of the tubes which enter the headers are bent in such a way that the tubes enter all of the headers at the same height, thereby making the circulation the same in each header. The boiler is built of A. S. M. E. Code material throughout to meet all of the requirements of the Code.

The boilers for 375 lb. pressure first considered were 14-high and 48-tubes wide with the two lowermost rows of tubes exposed for their full length to the furnace, with a horizontal baffle above the second row of tubes exposed from the downtake headers to the bottom of the inclined baffle between the first and second passes, the superheater being placed in the first pass above six rows of tubes. A change was made to a boiler 17-tubes high and 48-tubes wide with the six lowermost rows of tubes exposed to the furnace, with the superheater in the same position. This was done in order to secure the following operating advantages:

1st: The furnace temperature will be somewhat lower with the six lowermost rows of tubes exposed than with only two rows exposed for their full length to the heat of the furnace and with a high furnace of the sort that will be used this would tend to reduce the cost for brickwork maintenance. 2nd: In case a coal is burned which will cause an undue amount of slagging on the outside of the tubes exposing six rows of tubes for their full length will lead to less slagging difficulties than exposing the two rows for their full length. 3rd: In case of tube troubles due to impure feed water the tube loss would be less for a given amount of steam evaporated per hour from the boiler with six rows of tubes exposed both on account of causing the hot gases on striking the boiler tubes to be diffused over a longer length of tube surface and through providing a greater amount of boiler surface for a given amount of steam generated.

The flue gas temperatures for a given weight of steam evaporated per hour by the 17-high boilers with the six lowermost rows of tubes exposed will be but slightly lower than would be secured with the 14-high boilers with only the two lowermost rows of tubes exposed. A 16-high boiler with the six lowermost rows of tubes exposed would give about the same flue gas temperatures for a given weight of steam evaporated per boiler as a 14-high boiler with only the two lowermost rows of tubes exposed. The choice of the 17-high boilers with the six lowermost rows of tubes exposed was not therefore on the basis of the flue gas temperatures or the efficiencies, but on the broader basis of selecting a boiler which would give the best service under the conditions for use in connection with the economizers. If the 17-high boilers were fitted with a system of baffling that was considered for the 14-high boilers with the two lowermost rows of tubes exposed, the efficiency of the boilers for the same steam output under the average service conditions would be slightly more than one per cent higher than with the six lowermost rows of tubes exposed, and should no economizers be employed, this difference of efficiency would offset a considerable increase in cost of maintenance of brickwork and difficulties of operation.

P. Junkersfeld: Five considerations are stated on the third page of the paper. The third, "The probable effect of increased pressure upon reliability of operation and its flexibility in meeting anticipated load conditions with nigh over-all economy," and the fifth, "The economic balance of carrying charges and operating costs over a long period," are more or less interrelated. Under reliability of operation I assume that the authors have included maintenance. Apparatus of this sort naturally involves more maintenance or replacement than apparatus that has been tried out for a longer period of service. With the particular apparatus operating at 1200 lbs. steam pressure some troubles must be expected to develop during the early years, which means outages and units available less hours of the year.

Such outages do not reduce the total carrying charges per year, but will increase the carrying charges per kilowatt hour because if the turbine unit or boiler unit is out, for example, twice as many hours as a more seasoned piece of apparatus, it would double the carrying charges per kilowatt hour due to that particular apparatus. On the other side of the balance, if such turbine or boiler unit is running only half as many hours as a more seasoned unit in a year, the savings expected from the better fuel economy are much reduced. I take it, however, that these matters have been considered under considerations three and five, and the foregoing is submitted as a matter of emphasis on these two very important points in the paper.

Curve 1 Fig. 2, shows a very interesting and not usually appreciated fact, namely, that the total heat at 700 deg. fahr. decreases with increasing pressure. That is contrary to our ordinary expectations. Of course, after the careful analysis that the authors have made, we can see why it is so. However, considering Curve 1 and Curve 2 together, we see that after all, the heat available does increase with the pressure.

Curve 5 indicates that six hundred pounds should give the highest thermal efficiency. It is not clear to me whether this represents the expected performance from all types of turbines or only the particular type of turbine used in Weymouth Station.

On the third page it is stated that 1200 lb. was selected for the one new extra high pressure boiler. It would be interesting to know why 1200 lb. instead of say, 1000 or 1500 lb. was selected. There must have been some reason that led to the adoption of 1200 instead of something a little higher or a little lower.

There is frequently a tendency for too much standardization in power plants. It is a fact that the elements that go into a power plant like the elements that go into a suit of clothes,—the cloth, the thread and the buttons, should be thoroughly standardized, but you can never hope in my judgment to so far standardize power plants that they will fit every condition any more than you can hope to make a suit of clothes to fit every size of man. There would be a lot of misfits. There are a great many things that will be a good solution for one set of power plant conditions and one location, that might be a poor solution for another set.

The two most outstanding conditions that affect the proper design of plant for a given set of conditions are price of fuel and load factor. When I say price of fuel, I mean per thousand or million B. t. u., or some other equivalent that shows steaming value. Differential in price of fuel is usually a fairly definite thing. There is a substantial difference between the price of coal say in Boston, and price near the coal mines, over a long period of years. The price of coal on comparable basis may be two or three times as much in one locality as in another, and the same plant will not properly fit both localities.

Load factor, however, is a very elusive thing. It depends upon the general character of the business in the community. If every station were operated at exactly the natural consump-

tion of power within its proper area, it would be one thing, but we are no longer operating stations,—we are operating systems, and that means one, two, three, four or even more stations in parallel. These stations on the same system are in competition with one another. The better load factor is allocated to the station with the lowest operating cost, and to an extent depending on how much lower that station operates than the other stations. Operating cost, not fixed charges, govern this allocation, because fixed charges are established when you build the station. I am assuming now that such transmission and distribution handicaps as might exist between the various stations are all taken into account in allocating load between stations.

During the life of the equipment and just as any new station is usually lower in operating cost than older stations or units on the system, so may another new station five years later be still lower. Therefore future load factor on a station or unit is a very difficult question to decide, requiring judgment and experience and the very best attention and study.

Two other points in the paper would be interesting if amplified. First,—how is it proposed to protect the reheater from overheating should the turbine load be suddenly discontinued? Second,—In view of the fact that we can so effectively heat feed water by bleeding turbines, is there much to be gained with economizers?

The final results from the Weymouth Station are very promising, indeed, as given in the paper under ideal conditions, which are the only conditions under which they can be given at this time.

L. L. Elden: The Weymouth Station now under construction will be operated in conjunction with the rest of the system substantially as follows: The area served by the Boston Edison Company resembles a square looking at it from the water side, with L Street Station located substantially at the centre of the base line. The new Weymouth Station is located at the southern terminus of the base line about eleven miles from L Street. The present area served by the company is supplied from some 85 substations.

The ultimate growth of the system may be estimated broadly from the fact that the connected load is increasing yearly at the rate of about 100,000 kw. With this growth in view, it is conceived that eventually in the interest of economy another large generating station will be required north of the city, assuming, of course, that a suitable site can be found for the purpose.

To provide a suitable link between the new station and the remote points of the present system, it is proposed to construct a 110,000-volt ring around the system, starting from Weymouth and terminating at some desirable location on the north. Lines from L Street are serving all intermediate territory and will in the end be interconnected with lines from the Weymouth Station as business requirements may dictate.

Another project now being seriously considered is the introduction of hydro power in large quantities from the St. Lawrence district. The projected point of contact is at Framingham on the westerly side of our territory where it will intersect the 110,000-volt ring previously referred to. The route of this proposed ring will be exceptionally favorable for connection on the southerly side with the proposed superpower system developed by Mr. Murray and his associates during the war period.

We also find the location of the new station favorable to the supply of service to the New Haven and Boston and Albany Railroads in the event that the electrification of these roads becomes a reality in the future. With favorable conditions as regards coal, water and distribution facilities, we feel that it is conceivable that the entire proposed development of 300,000 or more kilowatts will be easily absorbed in the near future if all of the projects now in view actually eventuate.

Operating methods to which Col. Junkersfeld referred have not as yet been fully worked out, it being evident that to determine the best method of relaying and handling the two generators comprising each unit, when connected to the main system, will require considerable study. This has not yet been completed hence it is impossible at this time to indicate the reliability factor which will be developed in actual service. It would appear from studies made up to this time that the small 1000 pound unit may prove the only unreliable elment in the whole development since all other equipment is standard and already in extensive use. When, however, it is realized that the capacity of the high-pressure unit is only of the order of 2500 kw., its importance becomes negligible in a large system like ours, where many interconnections and emergency arrangements provide means for instant absorption of loads of far greater magnitude than would be involved in the event of failure of the unit in question. Under these conditions the question of fixed charges on spare capacity at this station to meet emergencies is not important since the reserves for the system as a whole will not be carried at any one location.

H. P. Liversidge: The details of the Weymouth plant which have been presented before this Convention, indicate the very practical consideration which has been given to its design in order that the generated power may be produced at lowest over-all cost.

In the consideration of new plant layouts, there is prone to be a tendency toward maximum operating efficiency with the possible sacrifice of other factors which have a decided bearing on investment costs and over-all operating costs. It is quite evident that these various factors have all been given primary consideration in this station layout.

I believe that while this plant incorporates some radical departures from standard design, it would seem to be a very safe change. It is evident that the high-pressure section, which embodies very special features, has been so arranged in its relation to the rest of the plant that if an unforseen complication should arise, no financial penalty will be imposed even if it becomes necessary to radically change or eliminate this special part of the equipment. This, in my opinion, is a most important consideration, and in the development of large central stations, I believe we should place ourselves in the position of doing not what we might like to do from the standpoint of highest efficiency alone, but what from a business standpoint is the safe thing to do,—investment and earnings being considered.

In designing a plant, another question to be considered is reliability—the plant must operate. We are in the position to-day where departures which involve radical changes from standard design must be so planned as not to penalize the high order of service which must be rendered to-day.

I believe that this plant design presents a combination of equipment which marks a step in advance in the application of high steam pressures, and, at the same time, eliminates the possibility of complications which may have their effect in either the lowering of reliability of service or increasing maintenance costs.

G. L. Knight: There is one point I think which has not been touched on and that applies particularly to those of us who were compelled to make our decisions, especially on steam conditions, somewhat before these later developments in boiler and steam turbine designs were made available. We are not going to suffer altogether thereby, I think, but can take advantage of some of these developments by using high-pressure turbines in stations where we have adopted lower steam pressures, installing some of our new boilers at 1000 or 1200 lb. pressure and exhausting the high-pressure turbines into our present steam lines at the line pressure.

H. W. Eales: Attention was called by Mr. Liversidge to the feature of the design at this station which permitted of the elimination of the high-pressure portion and of the substitution of the more standardized methods of design in the event of any difficulties with the design. Being connected with a power

station development which is utilizing pulverized fuel, I may say that the same factors have been carried out there. The design of the boiler house as laid out will permit of the substitution of any other form or method of burning coal which experience or advance in the art may direct.

Reference was made in the paper to the calculations of the Weymouth Station with reference to the choice of fuel combustion. It seems to the speaker that much of the discussion on the relative merits of pulverized fuel or stoker firing of coal in these super stations is still of the conjectural type. It is my opinion, therefore, that very little is to be gained by further discussion of the matter at this time. I would personally much prefer to delay comments until after experience with our particular station has demonstrated the results obtained.

The paper, on the sixth page pointed out two methods of securing power supply for station auxiliaries. It referred to the securing of power from the main station bus with attendant disaster to the auxiliaries in the event of general system trouble and the means of preventing that by using motor-generators floating between the house turbine bus and the station bus.

I wish to mention a third method, namely, that of using a saturated core reactor between the house turbine bus and the main station bus.

As a matter of purely experimental interest the speaker is greatly interested in the development of the Weymouth Station which uses an auxiliary alternator on the same shaft as the main generator. It may be pertinent to inquire if it is possible to go a step further and use a double-current generator, thereby deriving the excitation in auxiliary power by the same means.

F. Samuelson: Your plans are very bold and should give some really valuable information with regard to economy and reliability of extra high-pressure steam plant. It is very fortunate that it is relatively easy to ascertain the efficiency of the high-pressure end of the plant as the steam will be superheated on leaving the high-pressure turbine. With known inlet and outlet pressure and temperature of the steam it is readily found how much of the energy is converted into work. It is of course essential that the temperature measurements should be very carefully taken. There may be a slight error owing to want of exact knowledge of the specific heat of superheated steam at such high pressure of 1000 to 1200 lb. per sq. in., but this error will be small.

A very important matter in connection with the construction of steam plant at extra high pressures and temperatures, is the fact that the true elastic limit of most steels is lowered seriously as the temperature is increased. At a temperature of about 750 deg. fahr. the elastic limit may drop to half of that obtained at ordinary room temperature, and it is therfore very important that this loss of strength is understood when the factor of safety is settled upon.

As the strength of steel is so much affected by heat, I am strongly of the opinion that the temperature of the superheated steam should be controlled in some way. I have come across cases where the steam temperature has been above 800 deg. fahr. at the turbine stop valve, and where it has been necessary to lower the temperature by removing some of the superheater tubes, entailing increased drop of pressure across the superheater. I would advocate that the superheater be located in a chamber or compartment, preferable within the boiler itself, and provided with water cooled dampers, or other means which will control the flow of the hot gases. Where a reheater element is used this should be put in the same compartment as the steam passes through both these in series, and they ought therefore to be subjected to the same control. The temperature control should be automatic, regulated by some simple servo motor and pilot valve, which in turn is actuated by the temperature of the steam leaving the superheaters.

The arrangement you have adopted for providing power for the auxiliaries in the station is very economical and commendable. A somewhat similar arrangement is in use in the Birmingham Corporation power station on some 18,750-kw. sets, but in this case the auxiliaries are driven by direct current. A double unit d-c. generator set is driven direct from the main turbine, one unit provides excitation, the other supplies power for the auxiliaries.

With regard to the high-pressure turbine and its separate generator, I am not sure that this is the best ultimate arrangement. It would seem simpler to run both turbines at the same speed, putting them in tandem and connecting the two mechanically by a shaft having the usual claw coupling element at both ends. There need be no fear from out of alinement with this arrangement, and it does away with the generator, its losses, and some switching gear. The high-pressure turbine would in this case have more wheels than is indicated in the paper, but I think this would be in favor of economy, as with very high steam densities low steam speeds are desirable.

The design of the high-pressure turbine casing will no doubt present some difficulties with 1200 lb. initial and 375 lb. exhaust pressure, the mean internal pressure being in the neighborhood of 750 lb. It may be impracticable to split such a casing horizontally. The turbine set may preferably be placed at right angles from that shown on your plan with the high-pressure end nearest to the boiler house to shorten the steam pipes.

I see no reference in your paper to pre-heating the combustion air by the combustion gases on their way to the chimney. I believe this practise will be more and more taken up as it affords a means of cooling the combustion gases before they escape to the atmosphere, and also at the same time enables feed water to be heated to a higher temperature by bleeding before going to the economizer section of the boiler. With the higher feed water temperature the size of the economizer can be considerably reduced—part of this relatively expensive element is substituted for a cheaper air heating element.

There are some plants in this country in which air heating has been tried, but full information is still lacking. I think, however, that the sytem is right, and will eventually be successful.

I have not had an opportunity to check the curves giving the effect of steam pressure on the turbine thermal efficiency, but in general, I would say that they agree closely with similar investigations I have made, though not at such high pressures. I would, however, refer to curve No 4. which gives the efficiency ratio of a turbo-generator under different steam pressures, and believe that the slope of this curve is somewhat greater than it ought to be. In other words, that the efficiency of the turbine will be relatively greater at the higher pressures than indicated by this curve, which is to the good.

In conclusion, I would emphasize the great importance of proper control of the superheat in large stations such as yours at Weymouth. If such control is established the steam temperature may be raised some 50 deg. fahr. without any more risk than with a fluctuating temperature aiming at a lower temperature.

Joseph Pope: Answering the questions which Colonel Junkersfeld has asked, Curve No. 4 and consequently Curve No. 5, were prepared from data relating to the type of turbine to be installed in Weymouth Station. The manufacturers of the turbines, however, are not responsible for the high pressure end of these curves. Mr. Samuelson has also referred to Curve No. 4 suggesting that the slope is somewhat greater than he would anticipate. It is interesting to investigate the effect upon the problem in hand if the high pressure end of Curve No. 4 is raised as much as 5 per cent of its present indicated value, that is, from 72.5 per cent efficiency ratio at 1000 lb. abs. pressure to 76.0 per cent and if instead of being convex upward the curve is made a straight line of uniform slope between 300 lb. abs. and

1000 lb. abs. A table shows the result of this change most conveniently:

Abs. Press	Eff. Rankine Cycle Curve 3	Eff. Ratio Curve 4	Thermal Eff. Curve 5	Eff. Ratio as Modified	Thermal Eff. as Modified
100	30.75	83.30	25.61	83.30	25.61
200	33.75	82.80	27.92	82.80	27.92
300	35.30	82.10	28.99	82.10	28.99
365	36.20	81.49	29.48	81.50	29.49
400	36.60	81.15	29.68	81.22	29.73
500	37.50	80.00	30.00	80.35	30.12
600	38.27	78.80	30.12	79.48	30.40
700	38.83	77.45	30.07	78.61	30.50
800	39.40	75.90	29.90	77.74	30.60
900	39.77	74.28	29.52	76.87	30.52
1000	40.00	72.51	29.00	76.00	30.40

These are all slide rule figures, but sufficiently accurate for the purpose. Under the new conditions, the peak of efficiency comes at 800 lb. absolute, but this maximum is only 3.8 per cent higher than the efficiency at 365 lb. absolute, the throttle pressure actually selected, as against 2.1 per cent difference between the selected pressure and the maximum efficiency shown by Curve 5 in the paper, an amount clearly insufficient to justify the added expense. Although Curve 4, as stated, is based on data for the Weymouth machines, similar information was obtained concerning other turbine types, but the conclusions to be drawn from them were in nowise different.

The second question is "Why was 1200 lb. selected for the high-pressure equipment?" It was principally because of the equipment available, and because the curve of cycle efficiency is rapidly approaching the horizontal at that pressure. In actual operation the boiler pressure will vary with the steam output and consequently with the load on the pressure reducing turbine. It is probable that the normal operating steam output will be such that the boiler pressure will be about 1000 lb. although the safety valves are to be set at 1200 lb.

The third question "How is it proposed to protect the reheater from overheating should the turbine load be suddenly discontinued?" At the time this paper was prepared there had been no opportunity to completely investigate matters of this nature and the cut of the high-pressure boiler as shown is practically as it was first offered by the manufacturers. After suitable performance data were available, more thorough study of the interaction of the boiler, superheater, turbine and resuperheater at varying loads indicated some difficulty in controlling the reheat. With an initial temperature of about 700 deg. the exhaust temperature from the turbine at light loads is also very high. In consequence the temperature leaving the reheater would be considerably above what is commonly held to be safe. A change was therefore made in the design and location of the reheater in order to give the necessary control of the reheating, but as the regulation of the initial superheat is quite satisfactory the superheater was left substantially unchanged. It is purposed now to locate the reheater above the first two passes of the tube bank with the tubes running across the boiler. The reheater tubes are in two groups separated by a vertically sliding damper forming in effect an extension of the front boiler gas baffle. By varying the vertical position of the damper the combustion gases may be made to pass over more or less of the reheater surface, and the outlet steam thereby maintained at the desired temperature. It will be understood that this same arrangement effectually takes care of the situation which may arise from sudden loss of load on the high-pressure turbine.

The fourth question "Is there much to be gained by the use of economizers, since feed water can be effectively heated by bleeding turbines?" If it be granted, and we presume that it will be, that large commercial air heaters are still decidedly experimental and without practical demonstration of economic justification sufficient to warrant their general use, a combination of feed heating by extracted steam and by economizers seems to be the best arrangement. It is realized that economizers cost money, but surface type water heaters are by no means inexpensive. The heat reclaimed from flue gases is practically net gain, whereas that saved in bled steam is partially offset by the extra live steam that has to be supplied at the turbine throttle on account of the extraction.

Mr. Eales inquired if it is possible to use a double-current generator on the same shaft as the main unit and thereby derive the excitation and auxiliary power by the same means. Mr. Samuelson calls attention to a case in Birmingham where a double unit d-c. generator set is used in this manner. The use of a direct-connected exciter in conjunction with the auxiliary alternator was considered for Weymouth and while feasible enough was abandoned in favor of the present arrangement.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

CARBOHYDRATE PRODUCTION AND GROWTH IN PLANTS UNDER ARTIFICIAL LIGHT

The optimum conditions of light intensity for the growth of a great variety of plants have been determined using continuous artificial light. The intensity requirements of many plants is such that growth in artificial light alone is practicable in northern regions where winter sunlight is low and unreliable. Plants such as Easter lilies can be speeded up in time of blooming to bring them into the market at a certain date. The use of artificial light makes it possible to force blooming of two varieties at the same time so that hybrids may be more easily produced. There is a correlation between the intensity of continuous illumination and the quantity and nature of the carbohydrates produced in photosynthesis. The production of male or female flowers by some dioecious plants is dependent upon light intensity.—*Transactions, I. E. S.*

PRELIMINARY STUDIES IN THE RESPONSE OF PLANTS TO ARTIFICIAL LIGHT

Several thousand vegetable seedlings raised in flats and a larger number of flowering plants started from cuttings, raised in pots, were placed under ten 500-watt, 110-volt Mazda C clear from March 1, 1923 to April 4, 1923. The lamps were turned on at 9:00 p. m. and automatically shut off at 2:00 a. m. during the five weeks of the test. In addition to the artificial light the plants were exposed to sunlight. Check plants under sunlight only were duplicated in size and variety. As a result the plants bloomed approximately 8 days earlier than the check plants. The chemical tests show approximately the same amount of chlorophyll in both groups of plants. A progressive series of illustrations as well as curves plotted on charts show the remarkable growth and production of forced plants.

Light, one of the most important external factors in the growth of the plant, may in a few years be supplied economically to the commercial grower which will mean that the crops, both vegetables and flowers will be raised in a shorter period, that there will be earlier productions in the spring and also in the bringing of the crops in on scheduled dates.—*Transactions, I. E. S.*

CLEVELAND HAS NEW STREET LIGHTING DEMONSTRATION

To make available to municipal civic, and central station officials practical knowledge of street lighting, and to present to them fundamental principles governing the choice and installation of standard street lighting equipment by means of actual working models, a 2000-ft. section of E. 152nd Street, Cleveland, has been equipped with a street lighting research set-up.

The demonstration consists of some 40 different circuits and each circuit, with the lamps it controls, is a distinct type of installation. Lamps ranging in size from 100 candle power (1000 lumen) to 3000 candle power (30,000 lumen), spacings from 75 feet to 900 feet, mounting heights from 10 feet to 25 feet, and locations of units from 2 feet back of the curb line in successive steps to the center of the street, are all employed.

FIG. 1

The spectacular effect obtained at night with all systems turned on. The resulting illumination is approximately 5 times as much as any other street in the world.

FIG. 2—DAY VIEW OF CLEVELAND STREET LIGHTING DEMONSTRATION

This installation affords by far the most comprehensive demonstration of street lighting effects ever installed. It furnishes possibilities for instant comparisons between almost any two street lighting systems employing standard incandescent lamp equipment; its purpose is to offer concrete visual evidence to those interested in street lighting so that they may compare the types of system used in their own cities with any modern design, both types being demonstrated on the same street.

Through the cooperation of the Cleveland Illuminating Company, the Department of Light and Heat, City of Cleveland, and the Engineering Department, National Lamp Works of the General Electric Co., the demonstration is to be made available to all who are concerned with street lighting engineering; visitors to Cleveland are afforded an opportunity to inspect and study the various systems.

ELECTRICAL APPLIANCES AND LAMPS IN RESIDENCES

A report of a committee of the Association of Edison Illuminating Companies presented in September, 1923, makes available information concerning the number of lamps and appliances in dwellings in the northeastern part of the country as ascertained through surveys conducted in 1921 and 1922. 1497 residences were surveyed in 1921 and 5015 were surveyed in 1922. The surveys were made in five cities in 1921 and in eight cities in 1922. In each year approximately 100 central station employes visited dwellings and inspected the electrical equipment for this purpose. In addition to noting the number, rating and condition of all lamps and appliances, these men, in conference with householders, estimated the hours use throughout the year for each lamp and appliance. In 1922 graphic meters were installed in more than 100 dwellings chosen as being representative of the whole number surveyed, and records were obtained showing the actual consumption by lamps and by each kind of electrical appliance in these residences during a week in May.

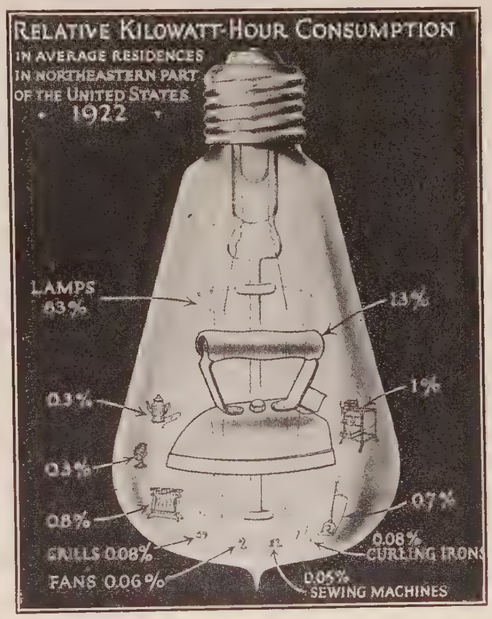

FIG. 1—ELECTRICAL APPLIANCES AND LAMPS IN RESIDENCES

The number of each kind of appliance per 100 medium class residences is shown by the committee report in Table 5 which follows:

TALBE V

PREVALENCE OF ELECTRICAL APPLIANCES IN MEDIUM CLASS RESIDENCES OF VARIOUS CITIES

Kinds of residences	Number of residences surveyed	City ranking	Number of appliances per 100 residences: Flatirons	Vacuum cleaners	Washing machines	Toasters	Percolators	Radiators	Grills	Sewing machines	Fans	Curling irons
			1922 Residence Survey									
Houses	1420	Highest	100	86	51	50	20	19	10	12	46	21
		Average	89	66	28	30	12	10	4	5	10	6
		Lowest	80	43	8	21	6	6	None	2	3	1
Apartments	190	Highest	100	72	31	59	28	4	4	16	6	8
		Average	99	62	20	45	22	3	2	10	3	5
		Lowest	98	51	8	31	16	3	None	4	None	3
			1921 Residence Survey									
Houses	550	Highest	99	70	59	41	21	13	8	10	11	5
		Average	94	58	41	32	13	9	6	6	9	3
		Lowest	..	42	16	18	3	8	3	3	3	..
Apartments	947	Highest	99	67	45	46	21	13	8	6	12	6
		Average	83	40	15	30	13	6	4	4	8	3
		Lowest	37	9	None	7	3	2	2	1	6	None

This indicates a wide range of appliance saturation as between different cities. Perhaps the most striking difference is exhibited in the case of washing machines, 51 of which were found in the 1922 survey in 100 medium class houses in one city, as compared with only 8 in 100 houses in another city. Doubtless variations in local conditions account for much of the difference here indicated, but the table makes evident the large extent to which labor-saving and comfort-promoting electrical appliances have yet to be supplied to the public.

Statistics shown elsewhere in the report indicate that in general electrical appliances are used more largely in houses than in apartments, and in general, though not without many exceptions, are used more largely in the higher class dwellings than in less well-to-do homes.

The report shows that the average watts of lamps used in the homes in the cities surveyed is of the order of 45 and approximates 1/2 watt per square foot of floor space for the lamps in general use exclusive of those which are installed but not ordinarily employed.

The report presents a rather elaborate analysis of the relative consumption of electricity by lamps and by appliances in the residences surveyed. The conclusions in this respect are reached by two methods:

1. Estimates made by each of more than 6000 householders in collaboration with the surveyors, showing estimated consumption by each electrical appliance and by lamps.

2. Deductions as to annual consumption from measured consumption by each kind of appliance and by lamps in about 100 representative residences during a week in May.

The distribution of the total consumption by appliances as ascertained from the combined surveyor-customer estimates and from the measured consumption during the test week appears in the committee's Table 17 as follows:

TABLE XVII

RELATIVE CONSUMPTION IN RESIDENCES BY APPLIANCES OF VARIOUS KINDS

	Surveyor-customer estimates	Measured during test week
	%	%
Flatirons	76.8	81.8
Vacuum cleaners	4.2	2.6
Washing machines	6.5	7.2
Toasters	4.9	5.3
Percolators	1.6	0.7
Radiators	1.5	1.4
Grills	0.5	0.003
Sewing machines	0.3	0.01
Fans	0.4	0.13
Curling irons	0.5	0.06
Miscellaneous	2.8	0.80
Total consumption by all appliances	100.0	100.00

The proportion of total annual residence consumption of electricity which is attributed by the committee to appliances as derived from the surveyor-customer estimates is 17 per cent and as derived from measurements in the test week in May is 20.6 per cent. The accompanying illustration indicates the relative annual consumption by lamps and by each of the more important appliances based upon the surveyor-customer estimates.

DAYLIGHT AS AN ATTENTION-GETTER

The danger signal advertisement is a unique way of using light to get (secondary) attention thrown over to an advertisement placed along the roadside. Warning those who pass by of approaching danger it fulfills a two-fold purpose by directing attention to the road and creating the tourists' good will toward the advertiser who erected it.

By day a ruby lens and reflector catches even the faintest rays of the sun and throws them in the motorist's eye. At night an alternating light throws the danger-red warning down the pike. The advertiser requests, "In case of damage, kindly notify the State Highway Commission."

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PACIFIC COAST CONVENTION

Del Monte, California, October 2-5, 1923

The 1923 Pacific Coast Convention of the A. I. E. E. at Del Monte, California, October 2–5, has passed into history as a most enjoyable and profitable Institute event for the fortunate two hundred and fifty-two members and guests who attended and participated in the excellent program of professional sessions and other interesting features, the plans for which had been carefully made and were coordinated and carried out in a highly satisfactory manner by the various members of the Convention Committee.

The geographical territory represented by those in attendance included eleven states, Canada, and Czecho-Slovakia.

TECHNICAL SESSIONS

There were four sessions at which papers were presented and discussed as outlined below:

First Session, Wednesday Morning, October 3

The Convention was called to order by Mr. Robert Sibley, chairman of the Convention Committee, who, after a short address of welcome, presented President Harris J. Ryan and Secretary F. L. Hutchinson, each of whom made brief addresses.

The following papers were then presented:

Mechanical-Electrical Construction of Modern Power Transmission Lines, by C. B. Carlson and W. R. Battey, Southern California Edison Co. (Presented by Mr. Carlson).

Special Features in the Design of Transmission Tower Lines as Imposed by Electrical Conditions, by W. Dryer, Pacific Gas & Electric Co.

Discussion of the above two papers followed by Messrs. F. G. Baum and W. Dryer, San Francisco; O. B. Coldwell, Portland; E. V. Pannell, New York; W. A. Hillebrand, Palo Alto, Calif.; and Harold Michener, R. J. C. Wood and C. V. Carlson, Los Angeles.

Researches Relating to High-Voltage Transmission, an illustrated address by President Harris J. Ryan, Professor of Electrical Engineering, Leland Stanford University.

Discussion by Dr. Charles P. Steinmetz.

110-kv. Transmission Line for Oak Grove Development of Portland Railway, Light & Power Co., by H. R. Wakeman and H. W. Lines, Portland Railway, Light & Power Co. (Presented by Mr. Wakeman).

Transmission Line Construction in Crossing Mountain Ranges, by M. T. Crawford, Puget Sound Power & Light Company. (Presented by Mr. John Harisberger, of Seattle).

Discussion of the above two papers by Messrs. R. J. C. Wood and Harold Michener, Los Angeles; J. P. Jollyman and Henry Bosch, San Francisco; W. S. Jennens and H. T. Plumb, Salt Lake; R. H. Halpenny, Riverside, Calif.; John B. Fisken and L. J. Pospisil, Spokane; and H. H. Schoolfield, Portland.

Insulation Design of Anchors and Tower Supports for 110,000-Volt, 4427-Ft. Span over Carquinez Straits, by L. J. Corbett, Pacific Gas & Electric Co.

Discussion of the above paper by Messrs. L. M. Klauber, San Diego; H. H. Schoolfield, Portland; and J. P. Jollyman, San Francisco.

Test Results on the Performance of Suspension Insulators in Service, by C. F. Benham, Great Western Power Co.

Discussion of the above paper by Messrs. W. A. Hillebrand and John A. Koontz, Palo Alto, Calif.; and J. E. Woodbridge, San Mateo, Calif.

Second Session, Wednesday Afternoon, October 3

(Mr. J. P. Jollyman, of San Francisco, presiding)

Some factors in the Power Problems of the U. S. A., an illustrated address by F. G. Baum, Consulting Hydroelectric Engineer.

This address, by Mr. Baum, was illustrated by stereoptican slides.

Discussion of above address by Messrs. L. F. Blume, Pittsfield, Mass.; O. B. Coldwell, Portland; F. G. Baum, San Francisco; and R. L. Hearn, Spokane.

Experience with Bearings and Vibration Conditions of Large Hydroelectric Units, by John Harisberger, Puget Sound Power & Light Co.

Water Wheel Construction and Governing, by E. M. Breed, Pelton Water Wheel Co.

A Study of Irregularity of Reaction in Francis Turbines, by R. Wilkins, Pacific Gas & Electric Company.

Discussion on the above three papers by Messrs. H. P. Treat, R. Wilkins and E. M. Breed, San Francisco; R. L. Hearn, Spokane; E. R. Stauffacher, R. J. C. Wood and John Sturgess, Los Angeles; and John Harisberger, Seattle.

Recent Hydroelectric Developments on the Southern California Edison Co., by H. L. Doolittle, Southern California Edison Co. (Presented by Mr. C. B. Carlson, of Los Angeles).

Upper Falls Development of the Washington Water Power Co., by L. J. Pospisil, Washington Water Power Co.

Hight-Voltage Switches, Bushings, Lightning Arrester Experience of the Southern California Edison Company on its 60,000, 150,000 and 220,000-Volt Systems, by H. Michener, Southern California Edison Company.

High-Voltage Circuit Breakers, by A. W. Copley, Westinghouse Electric & Mfg. Co.

Magneto-Mechanical Loads on Bus Supports, by L. N. Robinson, Stone & Webster, Seattle. (Presented by John Harisberger, of Seattle).

Discussion of the above three papers by Messrs. J. S. Thompson and A. J. Bowie, San Francisco; R. W. Sorensen, Pasadena; H. Michener and E. R. Stauffacher, Los Angeles; and R. M. Spwick, Schenectady.

Third Session, Thursday Morning, October 4

(Mr. John B. Fisken, of Spokane, presiding)

High-Voltage Insulation, by J. L. R. Hayden and C. P. Steinmetz, General Electric Co., Schenectady. (Presented by Mr. Hayden).

Discussion by Professor R. W. Sorensen, Pasadena, and Dr. C. P. Steinmetz, Schenectady.

Waterwheel Generators and Synchronous Condensers for Long Transmission Lines, by M. W. Smith, Westinghouse Electric & Manufacturing Company.

Methods of Voltage Control of Long Transmission Lines by the Use of Synchronous Condenser, by J. A. Koontz, Jr., Great Western Power Company.

Discussion by A. W. Copley, San Francisco; R. J. C. Wood, Los Angeles; and J. A. Koontz, Palo Alto.

Economic Considerations of Power Factor Control of Long High-Voltage Transmission Lines, by A. V. Joslin, Pacific Gas & Electric Company.

Discussion of the above paper by Messrs. F. G. Baum and J. P. Jollyman, San Francisco; and R. J. C. Wood, Los Angeles.

Performance of Auto Transformers with Tertiaries under Short-circuit Conditions, by J. Mini, Jr., Pacific Gas & Electric Company; L. J. Moore, San Joaquin Light & Power Corporation; R. Wilkins, Pacific Gas & Electric Company. (Presented by L. J. Moore and R. Wilkins).

Discussion by L. F. Blume, Pittsfield, Mass.

Transformers for High-Voltage Systems, by A. W. Copley, Westinghouse Electric & Manufacturing Co.

Discussion of the above paper by Messrs. R. W. Sorensen, Pasadena, and A. W. Copley, San Francisco.

Applications of Long Distance Telephony on the Pacific Coast, by H. W. Hitchcock, Pacific Telephone & Telegraph Company.

Telephone Transmission over Long Distances, by H. S. Osborne, American Telephone & Telegraph Co., New York.

Discussion of the above two papers by W. D. Scott, Sacramento.

Fourth Session, Friday Morning, October 5

After preliminary remarks, President Ryan asked Vice-President J. E. Macdonald, of Los Angeles, to act as Chairman.

Theory and Practise in High-Voltage Operation, by R. J. C. Wood, of Southern California Edison Company.

Discussion of the above subject by Messrs. J. E. Woodbridge, San Mateo; R. J. C. Wood, J. A. Lighthipe, and E. R. Stauffacher, Los Angeles; and J. P. Jollyman, San Francisco.

Group Operation of Systems having Different Frequencies, by E. R. Stauffacher and H. J. Briggs, both of the Southern California Edison Company, (Presented by Mr. Stauffacher).

Discussion of the above paper by Messrs. L. M. Klauber, San Diego; R. J. C. Wood, Los Angeles; P. M. Downing, San Francisco; and O. B. Coldwell, Portland.

Some Experiences with a 202-Mile Carrier-Current Telephone, by E. A. Crellin, Pacific Gas & Electric Company.

Carrier-Current Telephony on the High-Voltage Transmission Lines of the Great Western Power Co., by J. A. Koontz, Jr., Great Western Power Co.

Recent Developments in Carrier-Current Communication, by Dr. L. F. Fuller, General Electric Co., Schenectady.

Vice-President H. T. Plumb, Chairman of a previously appointed committee, consisting of himself and Messrs. J. A. Lighthipe and P. M. Downing, introduced the following resolutions, both of which were unanimously adopted:

Resolution in Memory of John A. Britton

WHEREAS, the Pacific Coast Convention of the American Institute of Electrical Engineers is being held in the section of our country which was the home of John A. Britton, who, for nearly a half century, served our industry and our profession in a manner that so endeared him to each and every one of us as to make him affectionately known as the "Dean of the Electrical Industry in the West."

THEREFORE, BE IT RECORDED that John A. Britton was loved and respected for his high devotion to duty and for his magnificent ideals of service while with us, to a degree rarely attained by men;

And, further, that a copy of this resolution be transmitted to his family, together with an appropriate message of profound sympathy and regard.

Resolution of Thanks to Members of Convention Committee

WHEREAS, in brilliant setting, in large attendance, in helpful well written papers and in friendships most inspiring, this Pacific Coast Convention of the American Institute of Electrical Engineers has surpassed previous conventions;

And because successful conventions do not happen but result from good engineering, systematic planning, professional cooperation and effective committee work;

THEREFORE, BE IT RESOLVED that this convention express its heartfelt appreciation and gratitude toward

1. The officers of the Institute and the members of the various committees who have functioned so admirably in planning the technical sessions, arrangements, entertainment, reception, registration, transportation and inspection trips.
2. The technical press, the *Electrical World*, the *Engineering News Record*, and the *Journal of Electricity* for their personal representation at this convention, and for the able assistance given by them on committee work.
3. The Hotel Del Monte for its courteous and gracious hospitality at all times during our convention.
4. The San Francisco Section, our most gracious host, for its untiring effort in sponsoring and seeing through a convention of such high character and quality, and so full of vital inspiration.

The Pacific Coast Convention Committee, which, by its thorough and effective work, earned the appreciation of all present, as expressed in the above resolution, consisted of the following members: President Harris J. Ryan. Honorary Chairman; Robert Sibley, Chairman; Allen G. Jones, Secretary. Messrs. H. W. Hitchcock, R. F. Monges, E. M. Breed, J. C. Clark, C. E. Fleager, M. C. McKay, George R. Murphy, L. S. Ready, J. E. Woodbridge, Henry Bosch, Jr., and the following, who, in addition to being members of the General Committee were chairmen of subcommittees in charge of the activities indicated: S. J. Lisberger, Papers; W. C. Heston, Arrangements; W. G. Vincent, Jr., Reception; W. B. Sawyer, Contests; W. P. L'Hommedieu, Banquet; R. A. Balzari, Registration and Transportation; H. W. Crozier, Big Creek Inspection Trip; R. R. Cowles and W. Winter, Bay Region Inspection Trips.

H. W. Crozier, of San Francisco, made a motion, seconded by L. J. Corbett, of San Francisco, that a committee be appointed to make recommendations in connection with the development of the Colorado River and extension of existing systems to conform to 60-cycle practise. Motion carried.

Chairman Macdonald called upon President Ryan, who, prior to adjourning the Convention, referred to the excellent addresses made by Dr. Jewett and Dr. Millikan, delivered at the banquet the previous evening, and expressed his appreciation for the "Aid to Hearing Set" furnished him by Dr. Jewett and coworkers, a great help to him in carrying out his work as President of the A. I. E. E.

Adjourned at 11:45 A. M., sine die.

Invitation from Czecho-Slovakia. During the banquet on Thursday evening, Dr. Vladimir List, Professor at the Technical University of Brno, Czecho-Slovakia, and Vice-President of the Czecho-Slovak Electrical Association of Prague, addressed the Convention, briefly expressing his appreciation of the opportunity of attending, and stating that he was commissioned by the Czecho-Slovak Electrical Association to invite the members of the Institute to attend the general meeting of that organization in Prague next July, stating also that there would be an electrical

exhibition and many other features that would be of interest to American electrical engineers.

Representatives' Session

On Wednesday evening a conference was held of officers and representatives of the various Institute Sections in Geographical Districts No. 8 and No. 9 (Pacific and Northwest Districts).

Vice-President J. E. Macdonald of the Pacific District presided, and the others in attendance included Messrs. T. H. Crosby, of Vancouver; John Harisberger, of Seattle; H. H. Schoolfield, of Portland; John B. Fisken and L. J. Pospisil, of Spokane; C. R. Higson, of Salt Lake City; Professor R. W. Sorensen and E. R. Stauffacher, of Los Angeles; H. W. Crozier, J. C. Clark, W. C. Heston, Allen G. Jones, J. A. Koontz, of San Francisco; also President Ryan, Vice-President Plumb, Mr. E. E. F. Creighton, Past Chairman of Meetings and Papers Committee, and National Secretary F. L. Hutchinson.

The meeting afforded an opportunity for a discussion of various matters relating to Institute activities and policies, in which all present participated until a late hour. Strong arguments were presented favoring Pasadena and Portland as the meeting place for the Pacific Coast Convention in 1924, and finally a committee of five was appointed, consisting of two members from the Northwest, two from Southern California, and Vice-President Plumb, of Salt Lake City, with the understanding that if the committee reached a unanimous recommendation it would be forwarded to the Board of Directors as the action of the conference. Later, at the banquet on Thursday evening, October 4, this committee reported that it unanimously recommended Pasadena for the 1924 Convention, the exact date to be fixed later, but preferably to be between October 15 and November 1.

Banquet, Thursday Evening, October 4

Over two hundred members and guests were present at the banquet held on Thursday evening. Mr. Robert Sibley, Chairman of the Convention Committee, presided as toastmaster, and during the dinner a number of interesting and amusing features were successfully carried out. At the conclusion of the dinner the principal event of the evening occurred, as reported elsewhere in this issue, namely, the presentation of the Edison Medal to Dr. Robert A. Millikan.

Entertainment

During the week ample entertainment was provided for the members and guests in attendance, including various automobile trips for the ladies, golf, tennis, swimming, and other recreation for all who desired to participate; also informal dancing each evening.

The principal golfing event was the competition for the John B. Fisken cup, for which there were forty-three entries, resulting in a tie between Messrs. S. J. Lisberger and P. M. Downing. The committee in charge decided that this tie should be decided by a putting match which was held in the dining room during the banquet on Thursday evening, and after a strenuous contest, resulted in a victory for Mr. Lisberger.

The ladies' putting contest, in which fifteen ladies participated, was won by Mrs. S. J. Lisberger.

A kicker's tournament was conducted and resulted in a tie between several contestants. This tie was also decided by a putting contest, the winner being Mr. P. M. Downing. Mr. W. G. Vincent was the "runner-up." Golf clubs were presented as prizes.

Excursions

Upon invitation of the Southern California Edison Company, about fifty members and guests departed on Friday evening in special cars for a two-day visit to the power plants in the Big Creek development.

Many other members participated on Saturday, October 6, in visits to the principal substations of the Pacific Gas & Electric Company and the Great Western Power Company in the San Francisco Bay region. Other individuals and small groups departed by special arrangement for visits to various other power developments in California and other Pacific Coast States.

Edison Medal Presented to Dr. Robert A. Millikan

The Edison Medal, which was awarded by the unanimous vote of the Edison Medal Committee in December 1922 to Dr. Robert A. Millikan for his experimental work in electrical science, was presented to Dr. Millikan immediately following the banquet held during the Pacific Coast Convention at Del Monte, California, on the evening of October 4.

Mr. Robert Sibley, Chairman of the Convention Committee, presided and he explained that Dr. Frank B. Jewett, who was President of the Institute last year when the award was made, had fully intended to be present and make the presentation address, but that the Japanese disaster had made a change in Dr. Jewett's plans necessary, and he was unable to leave New York at this time. Arrangements had been made, however, whereby Dr. Jewett would address the audience from New York by means of long distance telephony and amplifiers. Mr. Sibley then announced the program, which was carried out as follows:

National Secretary F. L. Hutchinson, who is also Secretary of the Edison Medal Committee, made a brief statement regarding the origin and history of the Edison Medal, concluding with the list of medalists.

Past-President Jewett then presented his address, from which the following is extracted:

To you President Ryan, to you Dr. Millikan, and to you, members and guests of the A. I. E. E. assembled at Del Monte, it is my pleasurable privilege to act as spokesman for those members of the A. I. E. E. who, like myself, are so unfortunate as to be absent from the 1923 Pacific Coast Convention.

But you will pardon me I know when I say that my pleasure is not untinged with regret—regret that although I may be with you in spirit and voice, circumstances beyond my control have prevented being with you in the flesh. But this is far from all, for who is the Medalist? To you he is the man the electrical engineers of America desire most to honor for his achievements in electricity; he is the great scientist, the great man in all those aspects of mind and character which represent greatness at its best. Perchance he is a friend which is but another way of saying you have met him. To me he is all this and infinitely more,—in some ways more probably than to any man living. For he was my teacher in those days of early manhood when I was seeking to acquire the tools of scientific knowledge which were to be my equipment for life.

But though I regret the miles which separate us, I experience a feeling of satisfaction in the knowledge that the very means which enable me to speak to you in this manner embodies much of the results of this man's work and is to a large extent the achievement of a group of men who derived instruction and inspiration from him.

And now Mr. President, I have a pleasant task to perform. In presenting our Medalist to you, and on behalf of the Edison Medal Committee, I desire briefly to recite the more important considerations which led to his selection.

Probably the best known and most noteworthy of Millikan's works are his so-called "oil drop" experiments, which were undertaken for the purpose of making precise measurements of e, that is, of the fundamental electrical quantity. These experiments proved conclusively that all electrons are alike and the results obtained by Millikan have been of inestimable value in the calculation of physical constants. In a word, the results which he obtained were revolutionary in character and eliminated almost completely the necessity for surmise and hypothesis in the interpretation of many phenomena and experiments.

Second only to the oil drop experiments is Millikan's work on photo-electric effect and his measurement of the so-called h constant. This is a universal physical constant of fundamental importance notably in the structure of the atom and in the relations between matter and radiation: its meaning is doubtless not yet fully clear. By identifying and measuring this constant in his experiments on photo-electric phenomena, Millikan made a very important contribution to modern physics.

More recently Millikan's work has tended toward a definite bridging of

the gap between light and X-ray phenomena. By this work he has pushed the ultra-violet spectrum down about two octaves or nearly, if not quite, to the long wave length X-rays.

All three of the foregoing monumental pieces of work are, I think, typical of Millikan's place in the scientific world.

Reference should also be made to the Physical Review Papers of 1923 on the coefficient of slip, the reflection of molecules, and the complete law of fall of a particle through a gas at all densities, definitely settling one of the historical problems of the kinetic theory, which has been incompletely treated both theoretically and experimentally by scores of papers during the past twenty-five years.

Among minor contributions may be named the establishment of the independence of the photo-electric effect upon temperature, the experimental proof of the fact that a light wave may impart an energy to a free electron of the metal, the relation between the contact potential of a metal and the photo-electric work-function, the determination of the law of Brownian movements in gases, the conditions for the detachment of two electrons from a single atom by the impact of an alpha or a beta particle against it; the non-existence of an intense penetrating radiation in the upper air, the extraction of electrons from metals by intense applied fields.

All of Millikan's important contributions to experimental physics have been in the region which is particularly important to electrical engineers, and the results which he has obtained have opened for us vast new areas for exploration and advance—exploration and advance which we can make with the assurance that our line of communication is based on a substantial bulwark of established fact.

Although Millikan's claim to recognition rests particularly on his experimental work, there are two other classes of achievement for which we here in America are greatly indebted to him. One of these is his work during the war and in the formation of the National Research Council, and the other is his influence as a producer of men.

He served throughout the war not only as a Lieutenant Colonel in the Signal Corps and as Director of all the scientific work which from time to time devolved on that branch of the Army, but he served also as a member of the Navy Department's Special Board on Anti-Submarine Matters, and as the executive head of the National Research Council, which was by Presidential proclamation charged with the duty of final advice and direction of the scientific work of the Government.

I was closely associated with him in all of his war work and I have not the slightest hesitancy in saying that to Millikan above all other American scientists is due the credit for whatever good resulted from the activities of America's scientists. He contributed not only from his own great store of scientific wisdom, but he was largely the driving force which directed the activity of others, including the Government Bureaus, into proper channels and stimulated individuals to an almost superhuman activity.

During the past two decades Millikan has done more to influence young men in the direction of scientific research along lines of clear thinking and with a high goal of prospective attainment, than anyone else in America. His characteristics of great humanity and of absolute intellectual integrity have been constantly in evidence.

Taken all in all it seems to me that the combination of inherent individual ability as a producer in his chosen field and his ability to influence human beings to an emulation of his ideas and methods, has placed Millikan in the very front rank of present day scientists.

At the conclusion of Dr. Jewett's remarks, President Harris J. Ryan presented the medal and certificate of award to Dr. Millikan.

Dr. Millikan's Response

Dr. Millikan said that when he reflected that preceding Edison medallists had been men of the type of Charles F. Brush, who had first shown the world that electricity might be used for city lighting, Alexander Graham Bell, whose invention was at the base of the whole vast system of modern communications, Frank J. Sprague, who had been responsible for the application of electric power to railway transportation, M. I. Pupin, who had made long distance telephony possible, J. J. Carty, under whose inspiration and leadership the telephone repeater and amplifier with all that they mean to the enrichment of modern life had been brought forth, and others of like achievement in the application of electricity to large industrial uses, he felt certain that there had been a misunderstanding or a mistake in connection with this year's award. For when he looked over his own thirty years of scientific effort he could find no industry which had grown out of his researches, nor even any which had been very immediately benefited by them. To make this altogether clear he outlined what his absorbing interests actually had been during these thirty years.

He then continued, "Since this survey certainly reveals nothing of great industrial consequence I am obliged to adopt either the mistake-theory, or, as an alternative, to assume that the American Institute of Electrical Engineers has this year been led to adapt a new policy—a policy of recognizing occasionally, at least, as something of vital, practical importance to the world, a type of activity which does not lead to immediate industrial advances. I am going to assume that this last hypothesis is correct, and in behalf of all workers in what is called the field of pure science, all those who are spending their lives in trying merely to ferret out nature's secrets and to better man's understanding of her laws, I wish not only to express my appreciation to the Institute for the award, but also to compliment it upon the breadth of its own vision and the service to science which it has done in recognizing before the public the value of this other field. For, in the final analysis, the thing in this world which is of most supreme importance, indeed the thing which is of most *practical* value to the race, is not, after all, useful discovery or invention, but that which lies far back of them, namely, 'the way men think'—the kind of conceptions which they have about the world in which they live and their own relations to it. It is this expanding of the mind of man this clarifying of his conceptions through the discovery of truth which is the immediate object of all studies in the field of pure science. Behind that object, however, is the conviction that human life will ultimately be enriched by every increase in man's knowledge of the way in which nature works, since obviously the first step in the beneficient control of nature is a thorough understanding of her.

"To illustrate my contention that the way men think is the most important and the most practical thing in human progress, I wish to consider briefly two great epochs in history in which significant changes have been brought about in man's conception of his world and of the place he occupies in it. The first epoch began just 450 years ago; for this year happens to be the 450th anniversary of the birth of Copernicus, or, as he was known in his native Poland, Nikolaus Copernik, a man who spent his his life not primarily in the pursuit of astronomy, but rather in the service of the church, for he was Canon of the Cathedral of Frauenberg. This man was more than any other responsible for changing the conceptions of mankind about what some men who call themselves practical would say had no bearing upon this life of ours at all, and yet there was not a political or social change in Europe during the two or three succeeding centuries which it did not affect.

"It is not strange that through all the ages up to the time of Copernicus the earth had been the center of man's universe, nor indeed that his whole thinking had been ego-centric—that he felt that the universe had been created especially for him with every bird and beast and flower ministering to his pleasure. Nor is it strange that in spite of this self-centered conception, surrounded as he was with mysterious forces, his philosophy of life had been a supinely fatalistic one,—that little idea had as yet entered his mind that he himself might have any real control over nature or that he had any responsibility for the shaping of human destinies. In all the ancient world three blind fates sat down in dark and dank inferno and spun out the lives of men. Man himself was not a vital agent in the march of things; he was but a speck tossed hither and thither in the play of mysterious, titanic uncontrollable forces. Even after the advent of Christianity no idea of the possibility of changing bad conditions by human effort gained access to his thinking. The best that he could do was to withdraw from the world and to cultivate his soul in a monastery, or to mortify the flesh after the manner of the pillar-saints, in the hope of reaping a reward in the next world for his piety.

"Now note first the simplicity of the process by which a change in his thinking begins to come about, and then note the result. The simplicity of the process has been characteristic of the advance of science in all ages. Careful observations such as men made in those days as well as this, had brought out difficulties in the explanations which had come down from the

past. The dome of heaven rotating about the earth and carrying the fixed stars, and other transparent crystalline domes carrying the planets and the sun and rotating at different speeds, were simple enough if one is not too insistent upon the requirements of mechanical engineering, but careful observation had shown retrograde motions, at certain seasons, of the planets outside the earth's orbit, which are actually due to the fact that the earth itself is at these times speeding between these outer planets and the sun at an angular speed greater than their own, thus causing them to seem to go backward. Such phenomena imposed impossible conditions upon the crystalline domes of the ancients unless the most complicated and grotesque assumptions were made. Copernicus wrote his only book to show that all these difficulties disappeared and all explanations came out vastly more simply if the earth is assumed to be but one of a number of little planets rotating once a day upon its axis and circling once a year about the sun. But realizing that this new conception might arouse opposition because it robbed man of his central position in the scheme of things he wrote to the Pope, to whom he dedicated his book, asking him to use his influence to defend him from those who might attack his theory 'because of some passage of Scripture which they had falsely distorted for their own purposes.' Here is a devoutly religious man 400 years ago of sufficient vision to see, even in the dim light of that shadowy age, that the foundations of real religion are not laid where scientific discoveries of any kind can disturb them, and who therefore keeps his mind open at all times to truth from whatever angle it tries to enter.

"But now look at the results of the introduction of this new way of thinking upon a subject which had apparently no industrial or commercial bearings whatever. The shock to tradition and to established custom was too great for the unseeing of his day as it is of ours. The Inquisition came and the frightful religious wars of the next two centuries, all because of the introduction of some new ideas into men's minds. Truly *the way men think* is the most practical concern in life, for all conduct flows from it!

"But slowly the truth prevailed, and for four centuries the sciences of celestial mechanics and of Newtonian dynamics had greater and greater successes until it became impossible for even the most narrow visioned and unintelligent of men to doubt the fundamental correctness of Copernicus' ideas even though they had been branded at their inception by popes and emperors and scholars, even as enlightened a one as Luther, as impious and untrue because they were 'in direct contradiction to the Scriptures.'

The second epoch of which I wish to speak is that in which "we live; for it is quite as extraordinary as that of Copernicus in the rapidity with which new conceptions are being introduced, and in the influence of these conceptions upon human life and conduct. Look at what has happened within my own life time in the field of physics, for example. When I started my graduate work in 1893 so sure were we of the physical foundations of our world, with its seventy-odd, unchangeable, indestructable elements, its well formulated laws of matter-physics and its equally firmly established laws of ether-physics, etherial and material phenomena being sharply and definitely differentiable, and the principles of the conservation of energy, the conservation of mass, and the conservation of momentum acting as nature's policemen to keep the universe running eternally within the law, that it was then being frequently said, often by the ablest of physicists, that it was probable that all the great discoveries in physics had already been made and that future progress was likely to arise only by increasing the refinement of our measurements. Then came, only two years thereafter, the capital discovery of X-rays, an entirely new phenomenon, having no relation whatever to refinements of measurement. And two years later came radio-activity, which has now completely exploded the notion of the eternal character of the atom and revealed a world in which many, if not all, of the so called elements are continually under-going change, spontaneously shooting off projectiles with stupendous speeds, speeds far beyond those which it had ever been thought possible that matter in any form could attain. And then three years later came the beginnings of the quantum theory, which has shown us unmistakably (so it appears) that in the domain in which electrons live even Newton's laws no longer hold. And then a few years later, through Einstein's insight or speculations, as you prefer, mass and energy became interconvertable terms, and now we are all agreed that our former sharp distinctions between material, electrical, and etherial phenomena have got to be abandoned. And, most important of all, from the amazing progress of physics has come more and more to the fore the idea that man has himself the ultimate ability to control for his own ends the changes going on in this changing world. How could it be otherwise when within a hundred years the very greatest of modern industries, that represented by the American Institute of Electrical Engineers, has been created through man's gaining year by year a larger and larger control of what used to be the most mysterious and apparently the most uncontrollable phenomenon of nature, the thunderbolts of Jove.

"And geology, too, is telling us the same kind of a story. It is but fifty years since the death of Lyell, a man who more perhaps than any other, first taught us to read the story of the rocks, yet now so well have we learned the lesson that to use a single illustration we count the exact number of years since the last ice age by the annual deposits on the shores of the Baltic Sea in just the same way as we obtain the age of a tree by the counting of its rings. And through all this expanding knowledge has come the definite evidence that man himself has been here perhaps a hundred thousand years, and yet that his extraordinary development, not physiologically, perhaps, but socially, has been exceedingly recent, much of it within a generation or two, since the developments in physics have given him control of the giant forces formerly wielded only by the Titans.

"And the developments in biology taking place under our very eyes tell the same story. Bacteriology has already banished some of man's most dreaded scourges. In the fields of agriculture, horticulture and animal husbandry, man now builds plants and fruits, and even animals almost to suit his taste. If he hasn't a drought-resisting wheat, a seedless orange, or a grape, he goes to work to make one. If he does not find an ox adapted to resist the Texas winds like the buffalo and to put on flesh like a Durham, he creates one. As a result, then, of the modern pursuit of pure science in all its branches—the following of that inner urge simply to know, to explore, to understand, two new ideas completely foreign to the ancient world and to many races of the modern world as well have come into our western civilization. The one is the idea of the possibility of progress, of continuous development; and the other the idea of man's ability to control and in the Providence of God (and I say it in all reverence) to determine to a large extent his own destiny, the idea of his own responsibility for the kind of an external world in which he lives. And if you wish to see the practical result of the changing of 'the way men think,' look at the difference between our own civilization and the static civilizations of Asia, where Nirvana is the goal of human life and a large fraction of the population reaches it quickly through starvation. Why is it that 'fifty years of Europe is better than a cycle of Cathay?' It is simply because in certain sections of the world, primarily those inhabited by the Nordic race, a certain set of ideas have got a start in man's minds, the ideas of progress and of responsibility.

"And these ideas have come about, I think, because in a few sections of the earth men have been led to follow simply *the urge to know*. First, to know this earth geographically, to explore it clear to the north pole and to the south pole even when they knew there was not the remotest prospect of growing wheat or potatoes there. But now the days of geographical exploration are gone, and yet it is the same urge which leads on the de-

scendants of these voyagers into the unknown—the astronomer to explore the heavens, however useless that may be, the physicist and the chemist to study the properties of matter and radiant energy whether he sees any immediate use for his results or not, the biologist to delve as far as he can into the secrets of life and of organic growth.

On behalf of all those who are working in the field of pure science, all those pioneers who are pushing out beyond the present frontiers of human knowledge—where a few years hence the engineer and the other builders of a future more perfect civilization than our own will follow them—on behalf of all those who are struggling on in this field, which does not often meet with large public appreciation, I extend my heartfelt thanks to the American Institute of Electrical Engineers for helping to educate the public up to its values by recognizing it with an occasional Edison award."

A. I. E. E. Directors Meeting

The regular bi-monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Friday, October 26, 1923.

There were present: Past-Presidents, William McClellan and Frank B. Jewett, New York; Vice-Presidents, W. I. Slichter, New York and W. F. James, Philadelphia; Managers, Harold B. Smith, Worcester, Mass., E. B. Craft, New York, H. M. Hobart, Schenectady, G. L. Knight, Brooklyn, N. Y., A. G. Pierce, Pittsburgh, W. K. Vanderpoel, Newark, N. J.; Secretary, F. L. Hutchinson, New York.

In the absence of the President, senior Vice-President Slichter presided.

The meeting opened with an expression of grief at the death, that morning, October 26, of Charles P. Steinmetz, a Past-President of the Institute; and a memorial resolution was adopted as printed elsewhere in this issue.

Reports were presented of meetings of the Board of Examiners held September 17 and October 22, 1923; and upon recommendation of the Board of Examiners the following action was taken: 258 Students were ordered enrolled; 161 applicants were elected to the grade of Associate; 5 applicants were elected to the grade of Member; 8 applicants were transferred to the grade of Member; 2 applicants were transferred to the grade of Fellow.

Upon the recommendation of the Meetings and Papers Committee the following Institute conventions for 1924 were authorized: Midwinter Convention, Philadelphia, February 4-8; Spring Convention, Birmingham, Ala., April 7-10; Annual Convention, Evanston, Ill., in June; Pacific Coast Convention, Pasadena, Calif., in October.

Mention was made of the remarkably successful convention held at Del Monte, California, October 2-5; and resolutions were adopted expressing appreciation of the services of the Convention Committee in making and carrying out the plans for the convention, and of the courtesies extended to the members and guests in attendance by the Pacific Gas and Electric Company, the Great Western Power Company, and the Southern California Edison Company.

Approval by the Finance Committee of monthly bills amounting to $28,725.71 was ratified; and a budget for the appropriation year commencing October 1, 1923, as recommended by the Finance Committee, was adopted.

In connection with an item included in the budget of $2000 covering expenses of members of district executive committees to meetings, the following resolution was adopted:

WHEREAS in the budget for the year beginning October 1, 1923, adopted today, an item has been included of $2000 for the traveling expenses of members of executive committees of geographical districts, as recommended by the Section Delegates at the Annual Convention in June 1923.

RESOLVED that this appropriation is made with the understanding that it will cover partial expenses to one meeting each year of each geographical district executive committee, on the basis of ten cents (10c) per mile one way from the home of the member to the meeting place.

Announcement was made of the award by the Institute of the Columbia University Scholarship in Electrical Engineering, to Mr. Dudley P. South, a graduate of Rice Institute, Texas.

Announcement was made of the appointment of Herbert Hoover as Honorary President of the International Engineering Congress, Philadelphia, 1926.

Reference to other matters discussed may be found in this and future issues of the JOURNAL under suitable headings.

Electric Drive for Ventilating Equipment

NOVEMBER MEETING OF THE NEW YORK SECTION

The New York Section of the A. I. E. E. will hold a meeting on the above subject in New York on November 14, 1923, under the auspices of the Industrial and Domestic Power Committee. The program will consist of several papers analyzing the design features of the fan and motor and discussing the application of ventilating fans in large public buildings, such as theatres, office buildings, hotels, etc.

F. R. Still, Vice-President of the American Blower Company has prepared a paper in which he analyzes the design of fans showing the relation between the speed of the fan and the other requirements of service.

C. A. Booth, Mechanical Engineer for the Buffalo Forge Company will present a paper on various types of fan design and construction and pointing out the developments which have taken place in this branch of engineering. He also brings out the difficulties experienced in adapting the a-c. induction motor when direct-connected to a fan.

Electrical engineers are very much interested in fan development, particularly in improvements which permit of higher speeds being used. The problem of a direct connected motor drive for fans is similar to problems in other fields which have been successfully worked out. It is desirable to couple together two pieces of apparatus which have essentially different speed characteristics. Success is obtained by variations in the design of both pieces of apparatus.

J. L. McK. Yardley, General Engineer, of the Westinghouse Electric & Mfg. Company will present a paper discussing the application of various types of motors to fan drive and showing the limitations in induction motor design for direct connection when very low-pressure low-speed fans are employed.

Prominent ventilating engineers will contribute to the discussion. The importance of this problem will appeal to many engineers, architects and builders and the New York Section is looking forward to a very interesting meeting.

Charles Proteus Steinmetz

In his home at Schenectady, New York, on the morning of October 26, 1923, at eight o'clock, Charles Proteus Steinmetz died from sudden heart failure. His fatal illness followed almost immediately after his return from a trip to the Pacific Coast, during which he attended the Pacific Coast Convention of the Institute, delivering a paper, in conjunction with J. L. R. Hayden, on "High Voltage Insulation."

Born in Breslau, Germany, on April 9, 1865, Dr. Steinmetz studied at the Universities of Breslau, Berlin and Zurich, specializing in mathematics, electrical engineering and chemistry. When twenty-four, he came to this country at the suggestion of an American student friend. While almost penniless and speaking but little English, he soon obtained a position in the drafting room of the Eickemeyer Works at Yonkers, N. Y. His advancement was rapid and when the company was absorbed by the General Electric Company in 1892 he was sent to the Lynn Works and in 1893 was transferred to Schenectady. He became Chief Consulting Engineer with the General Electric Company which position he held at the time of his death. In 1902 he was also appointed Professor of Electrophysics at Union College.

His work as an engineer and the bearing of that work on the rapid development of the art and science of electrical engineering is too well known to require detailed description here. As an author he produced many valuable treatises on such subjects as Transient Phenomena and Oscillations, Radiation, Light and Illumination, Electric Discharges, Waves and Impulses and numerous others—all the work of a master of research and analysis.

In addition to his work as a scientist and engineer, Dr. Steinmetz took an active interest in civic affairs. In 1912 he was appointed President of the Schenectady Board of Education and in 1915 was elected to the Common Council on the Socialist ticket and last year was the candidate for State Engineer and Surveyor.

To the Institute and its work he gave largely, having presented papers before many of its meetings from the early days down to the recent convention at Del Monte. He entered the A. I. E. E. in 1890 as an Associate and was elected a Fellow in 1912. He served on the Board of Directors as a Manager from 1892-1895 and as Vice-President from 1896-1898. In 1901 he was elected to the Presidency. He also took an active part in committee work, serving upon the Electrophysics, the Meetings and Papers, the Protective Devices Committees and the U. S. National Committee of the I. E. C.

Perhaps the most effective way of describing Dr. Steinmetz, his work and the place that work holds in the scientific world is through the expressions of appreciation by Dr. Frank B. Jewett, Past-President of the Institute, and by Thomas A. Edison. Dr. Jewett said:

In the death of Dr. Steinmetz, the electrical industry, not alone of the United States but of the world at large, loses one of its conspicuous and distinguished members.

Surmounting physical afflictions which would have justified a quiet life, he brought to the support of a fertile brain and a vivid imagination an almost incredible energy. For years he was a leader in the field of electrical research, particularly in matters pertaining to machine design and the transmission of energy, and his work in this direction has added much to our knowledge of the mathematical tools for solving complex electrical problems.

Thomas A. Edison said:

The world has lost one of its greatest practical mathematicians and the electrical industry will miss one of its shining lights.

At the meeting of the Board of Directors of the Institute held on the afternoon of October 26th, 1923, the following resolution was adopted:

WHEREAS the Board of Directors of the American Institute of Electrical Engineers has learned with deep sorrow of the death on October 26, 1923, of CHARLES PROTEUS STEINMETZ.

RESOLVED that as a tribute to his memory this minute be inscribed in the records: In the death this day of CHARLES PROTEUS STEINMETZ, President of the American Institute of Electrical Engineers in the year 1901-1902, the electrical engineering profession has suffered a grievous loss. His life was devoted to research, largely relating to the mathematical foundations upon which many of the developments in electrical engineering are based. His was always a master's contribution, whether in the field of machine design, the development of alternating-current theory and practise, or in pure or applied physics. He was a scholar, an author, a teacher.

In recognition of his services the American Institute of Electrical Engineers wishes, therefore, to record its realization of this loss to the Institute, to the profession and to the world, and to express its deep and heartfelt sympathy to his friends and associates.

Future Section Meetings

Lehigh Valley.—November 16 and 17, 1923. This will be the second meeting of the season, to be held at Pottsville, Pa. Speakers will be Mr. Wells, Chief Engineer for the J. G. White Corporation, on the subject of "Pine Grove Power Plant," and Mr. Lesser of the Madeira-Hill Coal Company, on the subject of "Mine Hoisting." On November 17th, there will be an inspection trip to the Pine Grove plant and to one or two coal mines in the district.

Syracuse—November 26, 1923. The meeting will be held at the Roof Garden of the Onondaga Hotel. Mr. George S. Anderson will address the Section and the Technology Club of Syracuse on "The Romance of Niagara."

December, 17, 1923. The place of meeting will be the same as that in November. Mr. Paul M. Lincoln, Director of the School of Electrical Engineering, Ithaca, N. Y., will speak on "Electrical Development in Retrospect."

Joseph Henry in the Hall of Fame

To the Membership of the A. I. E. E.

Some time ago Joseph Henry was voted a place in the Hall of Fame, New York City, and a tablet was erected in his honor.

Recently, the officers of the Hall of Fame invited the American Institute of Electrical Engineers to act as a sponsor body in providing a bust of Joseph Henry. The matter was presented by President Jewett to the Directors at the Swampscott Convention, and it was felt by the Directors that the Institute should accede to this request and act as a sponsor in raising the necessary funds.

The resolution of the Board in the matter was as follows:

"VOTED, that the President be authorized to appoint a committee with power to devise and put into effect, a plan for obtaining the necessary funds to provide and present a bust of Joseph Henry to the Hall of Fame."

The undersigned were appointed as this committee by President Jewett.

The Hall of Fame is a gift to the American people, and is located on University Heights, New York City, overlooking the palisades and the Hudson and Harlem river valleys. The Hall now contains sixty-three tablets, dedicated to the most famous American statesmen, scientists, authors, artists, and professional men. No person becomes elegible to election in the Hall of Fame until twenty-five years after his death. The names are selected by a group of men representing practically every state in the Union.

There will be no doubt in the minds of any one of the membership of the American Institute of Electrical Engineers that Joseph Henry who, by his researches and investigations, contributed so much to the fundamental knowledge which underlies all our modern electrical practise, is entitled to a position in the Hall of Fame, and that the provision of a suitable bust should be sponsored by the Institute.

It is the feeling of the Committee that each member of the the Institute would welcome an opportunity to honor his memory by a contribution toward the expenses of this bust.

The bust will be of bronze and a model has been made by Mr. John Flanagan, the famous sculptor, which meets the requirements of the Directors of the Hall of Fame. This bust is made from a statue by Mr. Flanagan showing Joseph Henry as a young man, in the attire of his time, as a teacher in the Albany Academy when he was engaged in carrying on his fundamental researches and experiments in electromagnetic induction.

The amount required for this bust is $1,600. Subscriptions from $1 up will be welcome.

It is hoped that the response to this appeal will be generous from all branches of the membership of the Institute.

Subscriptions should be made payable to and sent to Mr. G. A. Hamilton, Treasurer of the American Institute of Electrical Engineers, at 33 West 39th St., New York City, and marked "Subscriptions for Joseph Henry Bust."

JOHN J. CARTY,
JOHN W. LIEB,
E. W. RICE, JR.,
C. E. SKINNER,
LYMAN F. MOREHOUSE
Chairman, Joseph Henry Bust Committee.

The following word in regard to Joseph Henry will be of interest in this connection.

Joseph Henry was born in 1799. He began his scientific career while teaching in the Albany Academy, where he had only the apparatus which he constructed with his own hands. Independently of others he discovered the law of current induction and undertook the study of the electromagnet, which work prepared the way for all types of dynamo electric machinery, as well as for the telephone and the telegraph. He was the first to insulate the conducting wire itself, the first to adopt a spool for the winding of magnets, and the first to appreciate that the effect of the resistance of long lengths of wire and the passage of electric current could be minimized by properly proportioning the battery and his magnet windings to the length and resistance of the wires.

Later, as Professor of Physics at Princeton University, Henry studied further the subject of induced currents and discovered the oscillatory nature of the discharge of the condenser, which is of such great fundamental importance to-day.

Later he became Secretary of the Smithsonian Institute and, during the Civil War, rendered valuable services to this country in that capacity.

Joseph Henry was a many-sided man and, while his distinguished work touched upon a multitude of fields, it is what he did in connection with electromagnetism that is of greatest importance to the electrical engineering profession.

Do you Know this Man?

AMNESIA PATIENT REMEMBERS MAKING INVENTORIES OF HYDROELECTRIC PLANT EQUIPMENT

The Social Service Department of Charity Hospital at New Orleans, La., has asked the aid of engineering societies in trying to locate the family and friends of an amensia patient admitted to that institution April 2, 1923. The patient is known as Howard Grimes, as he carried a card bearing that name. He cannot recall family or friends but remembers having travelled extensively in the United States and Latin-America and believes that it was in connection with inventories of hydroelectric-plant equipment. In conversation with an engineer recently he revealed a broad knowledge of power house equipment.

Howard Grimes

"Mr. Grimes" is about five feet eight inches tall, weighs 140 pounds, has a florid complexion, reddish brown hair, blue eyes, perfect teeth, and is freckled on face and arms. He is probably about thirty years old, is well educated, and speaks Spanish. He is thoroughly familiar with New York and vicinity. He recalls having been in Vera Cruz, Tampico, Mexico City, Havana; Buffalo, Rochester, Chicago, Denver; Boston, Hartford, Bridgeport; Richmond, Newport News, Charlotte, Atlanta, Savannah and Jacksonville.

The card found on him was inscribed Howard Grimes, Jacksonville, Fla., state distributor for the Allco Rim Tool Company. He was employed by this company before going to New Orleans, where he collapsed at the Planter's Hotel, but they were unable to furnish any further information concerning him.

The Charity Hospital, which is making every possible endeavor to identify the man, thinks it possible that some information may be obtained from engineers with whom he may have come in contact.

The American Peace Award

ACTIVE COOPERATION OF ENTIRE A. I. E. E. MEMBERSHIP IS SOUGHT

The American Peace Award, created by Edward W. Bok, offers One Hundred Thousand Dollars ($100,000) to the author of the best practicable plan by which the United States may cooperate with other nations to achieve and preserve the peace of the world.

The question of cooperation by the Institute in this work was submitted to the Board of Directors at their meeting of August 2nd. As the plans of the Policy Committee of the Award explicitly provide that cooperation does not in any way commit an organization to any particular program or method of international cooperation, the Directors voted that a representative of the Institute on the Cooperating Council of the American Peace Award be appointed. Past-President Harold W. Buck, Chairman of the Institute's Public Policy Committee, was selected by President Ryan. Meetings of the Cooperating Council have been held and plans evolved for obtaining nation-wide publicity and cooperation, including the submission to the citizens of the United States of a referendum vote on the approval of the plan eventually to be selected by the jury of award. Arrangements will be made to take the referendum in January and every A. I. E. E. member is most earnestly requested on receipt of the approved plan and ballot to record his vote at that time without delay. Over seventy-five organizations are now cooperating in this work and the number is increasing daily.

Complete information relative to the Award follows:

The award is offered in the conviction that the peace of the world is the problem of the people of the United States, and that a way can be found by which America's voice can be made to count among the nations for peace and for the future welfare and integrity of the United States.

The purpose of the award is to give the American people from coast to coast a direct opportunity to evolve a plan that will be acceptable to many groups of our citizens, who, while now perhaps disagreeing as to the best method of international association, strongly desire to see the United States do its share in preventing war and in establishing a workable basis of cooperation among the nations of the earth.

FOUR SUBSIDIARY AWARDS

Since the plan finally selected by the Jury may be a composite of more than one plan, there are also offered, in addition to the main award of one hundred thousand dollars ($100,000), second, third, fourth and fifth awards of five thousand dollars ($5,000) each for any plans or portion of plans used by the Jury of Award in a composite plan.

If the Jury accepts one plan in full, making no additions to it from other plans, no subsidiary awards will be made.

CONDITIONS OF AWARD

Qualifications of Contestants

The contest is open to every citizen of the United States, by birth or naturalization.

Plans may be submitted either by individuals or by organizations of every kind, national, state or local.

Scope of the Plan

The winning plan must provide a practicable means whereby the United States can take its place and do its share toward preserving world peace, while not making compulsory the participation of the United States in European wars, if any such are, in the future, found unpreventable.

The plan may be based upon the present covenant of the League of Nations or may be entirely apart from that instrument.

Time and Manner of Payment of Award

The purpose of the Award is twofold: first, to produce a plan; and secondly, to insure, so far as may be, that it will be put into operation.

The Award is, therefore, to be made in two payments: fifty thousand dollars ($50,000) will be paid to the author of the winning plan as soon as the Jury of Award has selected it. The second fifty thousand dollars ($50,000) will be paid to the author if and when the plan, in substance and intent, is approved by the United States Senate; or if and when the Jury of Award decides that an adequate degree of popular support has been demonstrated for the winning plan.

The question of whether amendments which may be made in the Senate materially affect the intent of the plan submitted, and the acceptance or rejection of these amendments are left entirely to the judgment of the Jury of Award.

The second half of the award or fifty thousand dollars ($50,000) shall not be deemed to have been won unless the conditions above mentioned as to the approval of the plan shall be fulfilled on or before March 4, 1925.

The subsidiary awards are to be paid upon the same basis as the principal award; that is, twenty five hundred dollars ($2,500) will be paid to the author at the time the first fifty thousand dollars ($50,000) is paid, and the remaining twenty-five hundred dollars ($2,500) if and when the composite plan, in substance and intent, shall have been accepted by the Senate of the United States: or if and when the Jury of Award decides that an adequate degree of popular support has been demonstrated for the winning plan.

Form for Plan

Plans submitted should not be in the form of bills, resolutions, or treaties suitable for presentation to the Senate.

The paper submitted may include not only the exposition of the plan, but also argument for it.

A summary of not exceeding five hundred words must accompany every plan.

Length

The total number of words submitted, exclusive of the summary, must not exceed five thousand (5,000).

Rules for Contestants

Only one plan may be submitted by any one contestant.

Manuscripts must be typewritten, and on only one side of the page.

Manuscripts must not be rolled.

They must not be accompanied by letters.

They must not bear the name of the author or contain anything by which the author might be identified. Each manuscript must have attached to it a plain sealed envelope containing the author's name and address. As they are received, the manuscript and envelope will be marked, for identification, with the same number. The envelopes will not be opened until the Jury of Award has made its selections. Hence the receipts of manuscripts cannot be acknowledged.

No manuscripts will be returned. No postage for the return of manuscripts should therefore be included by the sender.

Time Limitation

All manuscripts must be received at the office of the American Peace Award by twelve o'clock midnight on November 15, 1923. Manuscripts received after that time cannot be considered.

It is expected that the Jury will be able to announce the selection of a plan for the first part of the Award in time for the plan to be presented to the Senate early in 1924.

Right of Publication

The submission of any manuscript, whether or not it receives an Award, shall give to the Committee full rights to publish the same in such manner and at such time as it may choose.

COOPERATING COUNCIL

Working in direct cooperation with the Policy Committee of the American Peace Award are the most prominent and effective organizations, civic, religious and economic, throughout the United States.

A cooperating council has been formed for the American Peace Award, consisting of one delegate from each of these organizations.

JURY OF AWARD

The personnel of the Jury of Award is as follows: Colonel Edward W. House, representative of Ex-President Wilson to the European Governments; General James G. Harbord, President of the Radio Corporation of America and Chief of Staff of the A. E. F. during 1917-18; Ellen F. Pendleton. President of Wellesley College; Roscoe Pound, Dean of Harvard Law School; Elihu Root, former Secretary of War and Secretary of State; William Allen White of Kansas, editor; Brand Whitlock, former Ambassador to Belgium.

THE REFERENDUM

When the plan is finally selected by the Jury of Award and the vote of each citizen is sought it is sincerely hoped that every A. I. E. E. member will give the plan the careful attention it deserves, cast his vote, and do so without delay as ballots must be in before the end of January 1924 to insure presentation of the result to the Senate in February.

Superpower Conference

SECRETARY HOOVER'S PROGRAM INDORSED BY PUBLIC SERVICE COMMISSIONERS OF TEN STATES

At a conference called by Secretary Hoover with the approval of the President the preliminary discussion was had of cooperative steps by Federal and State authorities toward the approval of superpower development in the Middle Atlantic and New England States. At the meeting which was held in the Board Room of the A. I. E. E. on Saturday afternoon October 13, the representatives of Public Service Commissions in ten northeastern states were present. Mr. Hoover emphasized the fact that this conference was not to be conceived as more government in business but as a step to obtain coordination between public authorities and industries to secure consummation of a great advance in the development of service to the public.

In his statement Mr. Hoover spoke in part as follows:

"The reason and need for this discussion is simply that engineering science has brought us to the threshold of a new era in the development of electric power. This era promises great reductions in power cost and wide expansion of its use. Fundamentally, this new stage in progress is due to the perfection of high-voltage longer transmission and more perfect mechanical development in generation of power. We can now undertake the cheaper sources of power from water sources further afield, such as the St. Lawrence and cheaper generation from coal through larger and more favorably placed generation plants. We can secure great economies in distribution through the interconnection of load between systems for thus we secure a reduction of the amount of reserve equipment, a better average load factor through pooling the effect of day and seasonal variations together with wider diversification of use by increased industrial consumption. We can assure more security in the power supply from the effect of coal strikes and from transportation interruptions.

"All this means the liquidity of power over whole groups of States. At once power distribution spreads across state lines and into diverse legal jurisdictions. We are, therefore, confronted not only with problems of the coordination in the industries of their engineering, financial and ownership problems, but also with new legal problems in State rights and Federal relations to power distribution.

"This super development of great areas of cheaper power has been dramatized by those less familiar with the problem, as the construction of great power highways traversing several states into which we should pour great streams at high voltages from great giant water power or central steam stations to be distributed to the public utilities and other large users along the lines of these great power streams. This, indeed, serves perhaps to picture what is meant by super power development. As a matter of practical fact, however, the natural development of this situation lies first in the inter-connection of power supplies between the existing great utility systems, and second, in common action for the erection of large units of production at advantageous points for the mutual supply of two or more of the present systems and in the development of such great water powers as the St. Lawrence.

Mr. Hoover then outlined the results of the Superpower Survey made at the instigation of our engineering societies by the Federal Government into the possibilities of more comprehensive and coordinated development in the Northeastern states.

"This new era of advanced projects is no theorists' or promoters' dream. It is a basic fact unanimously supported by our engineers; agreed to by the responsible men in the industry. . . . The electrical companies, under the regulation of the Public Service Commissions, have already made excellent progress in the application of superpower principles in many localities. . . . This being the case—one purpose of this conference is to consider—why does this development in this, the greatest power zone of our country, where the greatest saving can be made, not make progress?

"Whatever the fault may be it is the purpose of this conference to give preliminary consideration to the problems and principles that might be adopted in interstate relations; to discuss what measures can be devised to assure this needed development and what obstacles in its realization can be removed.

"One of the first principles we must realize is that the whole of this development implies the free flow of power. We have thus at once created at least a physical and economic interstate question. This great development of so much public interest cannot come about unless there is a complete liquidity in movement of power back and forth across the boundaries throughout the whole of the United States. Without this we shall have permanently a larger cost of power and less expansion in its service.

"I am not here to advocate Federal super regulation of interstate movement of power. I believe that power development and distribution would find its greatest solution in coordinated State regulation, perhaps with assistance and cooperation of the Federal Government. . . . "

Mr. Hoover then called on W. S. Murray to outline the physical problems and gains in the contemplated Superpower Zone. The legal phases of the problem were discussed by E. G. Buck-

land, Vice-Pres. of the N. Y., N. H. & H. R. R. The chairman of the New York Public Service Commission, W. A. Prendergast, pledged the cooperation of that body.

The following Commissioners also pledged support: W. T. Gunnison, New Hampshire; R. T. Higgins, Connecticut; W. C. Bliss, Rhode Island; E. E. Stone, Massachusetts; W. D. Ainey, Pennsylvania; W. A. Dutton, Vermont; H. V. Osborne, New Jersey; C. E. Gurney, Maine; E. B. Whitman, Maryland. The executive manager of the N. E. L. A., M. H. Aylesworth and O. C. Merrill executive secretary of the Federal Power Commission also spoke in indorsement of the project.

The program for a larger conference to be held in the near future is being arranged by Secretary Hoover.

New Moore School of Electrical Engineering at University of Pennsylvania

Prior to the fall of 1914, the courses in electrical and mechanical engineering at the University of Pennsylvania were given in a single department of the Towne Scientific School, known as the Department of Mechanical and Electrical Engineering. The growth in the number of students taking electrical engineering, together with the steadily increasing importance of this branch of the engineering field, led the Trustees of the University in the fall of 1914 to establish an independent department of Electrical Engineering.

Important as were the changes effected in 1914, of much more far reaching significance has been the recent change in the courses at the University whereby in the future these courses in Electrical Engineering will be given in an independent school, under the management of the University. This new school, which makes the thirteenth in the University, has been established under the provisions of the will of the late Alfred Fitler Moore of Philadelphia.

By the terms of Mr. Moore's will, his estate was to be used for the purpose of founding a school of electrical engineering as a memorial to his parents.

By the terms of the agreement between the Trustees under the will of Mr. Moore and the Trustees of the University, the entire estate left by Mr. Moore, amounting to upwards of $1,500,000 becomes, in effect, an endowment for this new school. For the present needs of the new school no new building will be necessary, since the laboratories in the Engineering Building formerly occupied by the Electrical Engineering Department, together with certain additional space in this building will be used by the new school.

The income from this endowment will be used primarily to develop undergraduate instruction in Electrical Engineering and for graduate instruction and to encourage research work on the part of both faculty and students.

The Provost and the Board of Trustees, in recognition of his energetic services as Director of the Department of Electrical Engineering for the past nine years, have appointed Dr. Harold Pender as the first Dean of the new School. Dr. Pender possesses to an unusual degree the qualifications for this new and important post. He has not only had a wide practical experience in the engineering field in connection with varied engineering developments and investigations, but he has also had an extended and successful teaching experience.

Dean Pender was graduated from Johns Hopkins University in 1898. The next three years, he spent in graduate work at that institution under Professor Henry A. Rowland, and obtained the degree of Doctor of Philosophy in 1901. This was followed by several months of important research work in France. Upon his return to this country, he took up practical work in engineering, and was connected in turn with the Westinghouse Electric and Manufacturing Company at East Pittsburgh, the New York Central Railroad and with Mr. Cary T. Hutchinson of New York City, with whom he was associated for five years, after which period he was appointed professor of electrical engineering at the Massachusetts Institute of Technology, becoming director of electrical engineering research at that institution in 1913. In 1914 he was called to the University of Pennsylvania as director of the newly created Department of Electrical Engineering. Dean Pender is a fellow of the American Institute of Electrical Engineers, and has served on a number of its committees, notably as Chairman of the Standards Committee. He has contributed articles on scientific and engineering subjects, is the author of several well known text books and is the editor-in-chief of *Pender's Handbook for Electrical Engineers.*

For the present year, two additional members have been added to the regular teaching staff namely Mr. Nicholas Minorsky and Mr. John B. Clothier, Jr. Mr. Minorsky comes to the University as Assistant Professor of Electrical Engineering. Mr. Minorsky obtained the degree of E. E. from the Imperial Polytechnic Institute, Petrograd, Russia in 1914 having previously studied at the Naval College at Petrograd and at the University of Nancy, France. On the outbreak of the World's War he entered the Russian Navy. In 1917 he was the representative of the Russian Navy on the Inter-allied Committee for Inventions in Paris, France. Following the Russian Revolution he came to this country, and was first employed by the Sperry Gyroscope Company as a consulting engineer and later was employed by the General Electric Company as research engineer in the Research Laboratory at Schenectady. Since December, 1921 he has been engaged in development work for the Bureau of Construction and Repair, U. S. Navy Department. He comes to the University directly from the completion of a successful test of an automatic stearing gear which he has invented, and which is now installed on the *U. S. S. New Mexico.*

Mr. John B. Clothier, Jr., who was a half-time instructor in the Electrical Engineering Department last year, has this year been appointed full-time instructor. The present staff of the Department now numbers a total of ten, namely, two full-professors, three assistant-professors and five instructors.

In addition to the regular staff of instructors, the Moore School plans to have experts, regularly employed in the industry, give special courses of lectures during each term of the school year. For the first term of this year, Mr. William Arthur Del Mar, chief engineer of the Habirshaw Electric Cable Company of New York, has been appointed special lecturer on Wires and Cables, and Dr. Albert W. Hull, Research Physicist of the General Electric Company at Schenectady, N. Y., has been appointed special lecturer on Vacuum Tubes and their Applications.

As an incentive to research work on the part of the members of the staff, a number of "staff fellowships" have been created. These fellowships, each of which carries a substantial stipend, are open to any member of the staff who is carrying on creative work along lines approved by the Dean.

Opportunities for graduate work, for those students who may desire to pursue their studies beyond the regular under-graduate course, will also be provided. In addition to the graduate courses to be given in electrical engineering, advanced courses of study and laboratory facilities are also available in physics, chemistry, mechanical engineering and civil engineering, and also advanced courses in mathematics, and other sciences.

The registration in the Moore School of Electrical Engineering as of October 19th, 1923, was as follows:

Freshmen	55
Sophomores	36
Juniors	29
Seniors	20
Total	140

Aldred Lectures at M. I. T.

The first of the Aldred Lectures at the Massachusetts Institute of Technology, established by Mr. J. E. Aldred, who carried to a successful conclusion the immense hydroelectric development at Shawinigan Falls on the St. Maurice River in Canada, is announced for the afternoon of November 9th. Mr. Gerard Swope, a Technology graduate, of the class of 1895, president of the General Electric Company, will deliver the first of the lectures. Other eminent industrialists and engineers are to complete the program for the first year which will consist of twelve lectures. President Stratton has appointed Professor D. C. Jackson, Head of the Department of Electrical Engineering and Professor Vannevar Bush, in charge of graduate work in Electrical Engineering, to cooperate with Mr. Aldred in establishing the lectures. A number of prominent men have been invited to give papers in a schedule that is being arranged to cover the next five years.

Power Survey for Pennsylvania

The Pennsylvania legislature at a recent session made an appropriation for an "outline survey" of the energy resources of the state and methods for their utilization. The Giant Power Survey Board created is requested to report at the January 1925 session of the Legislature. Morris L. Cooke, consulting engineer of Philadelphia has been appointed director of the survey.

As an indication of the deep interest in this power study felt both by Governor Pinchot, who acts as chairman of the Board and by the Legislature, the appropriation to carry on the work has been obtained in spite of the urgent necessity for retrenchment. It is felt that the measure of success obtained will be largely conditional upon the interest taken in the work by the engineering profession. The Board will greatly appreciate suggestions and help from Institute members. The main office of the Survey will be in the Capitol at Harrisburg. A district office has been opened in the Fuller Bldg., 10 S. 18th St., Philadelphia.

Second Exposition of Power and Mechanical Engineering

The number, diversity and interest of the exhibits of the Second Exposition of Power and Mechanical Engineering promise to far excell those of the first exposition held in December 1922. The 1923 Exposition is to be held in the Grand Central Palace, New York City, from Monday, December 3, through Saturday, December 8th. The week of the Exposition will be an active period for engineers, for during that time meetings of the American Society of Mechanical Engineers and the American Society of Refrigerating Engineers will be held. These meetings insure an attendance of influential engineers and executives. In addition, the National Association of Stationary Engineers, and its affiliated bodies, is organizing the interest of their membership, for last year these men, who are so vitally concerned with the operating problems, found the exposition to be of great educational value.

The exhibits will be supplemented by an extensive program of moving picture films to be presented in cooperation with manufacturers. About two hundred exhibitors have signed contracts for space at the Exposition. The devices and apparatus to be exhibited cover the field of power and mechanical engineering from the handling of the coal at the power plant until power is turned into work.

Exposition of Decorative and Industrial Arts

An international exposition of Decorative and Industrial Arts will be held in Paris in the Spring of 1925 under the auspices of the Ministry of Foreign Affairs and the Ministry of Commerce and Industry. The United States has been officially invited to take part in the exposition which it is believed will afford an excellent opportunity for showing American progress in decorative and industrial art.

American Engineering Council

MORTIMER E. COOLEY RESIGNS AS PRESIDENT OF AMERICAN ENGINEERING COUNCIL

Resignation of Mortimer E. Cooley, Dean of the College of Engineering and Architecture of the University of Michigan, as president of the American Engineering Council of the Federated American Engineering Societies was announced at the opening session of a two-day meeting of the Executive Board of the Council held in Rochester, N. Y., October 12.

Dean Cooley, in presenting his resignation to the Board, said that he retires on account of ill health. He also made it known that he has been granted leave of absence by the University of Michigan for the second half of the academic year of 1923-1924.

Succeeding Herbert Hoover as president of the Federated American Engineering Societies, two years ago, Dean Cooley, now in his sixty-ninth year, has been identified with numerous national undertakings in the public service, notably the investigation into the two-shift system in continuous industry, and the study of coal storage now in progress throughout the country. During his term the Federation has become the spokesman of the engineering profession of America in public affairs and foreign relations, in both of which fields extensive activity is being carried on.

With his retirement as principal executive of the Engineering Federation, Dean Cooley rounds out a career of almost half a century in the service of the state, of education and of his profession.

The resolution, the adoption of which followed the expression of glowing personal tributes by leading members of the Executive Board, and which was in the nature of an address to Dean Cooley, follows:

Every member of the Executive Board of the American Engineering Council whose deliberations you have led and guided for the past two years listened with the deepest regret to your announcement of the necessity of laying down the duties of the office of President of the Federated American Engineering Societies at the close of this year. Could any reassurance of our support of you and your policies have changed that decision, such assurance would have been at once unanimously tendered.

You took the responsibilities and burdens of our leadership at a most trying hour and in our behalf you have sacrificed both time and health.

With a lifetime already devoted to the unification and upbuilding of our profession, you were our outstanding choice to assume the responsibilities of the guidance of our policies. Our faith in you has been more than justified. Coming to us at a time when our organization was almost unknown and of little influence, through your personal prestige and because of your clear vision of the possibilities of service and achievement by a united profession, the Federated Societies have now reached an unassailable position of dignity, respect and public confidence.

For all this and for the steadfastness with which you have revealed your vision to us and to our profession, we thank you.

Though consoled by your promise to still be with the work of the Federated Societies, we shall miss your leadership and something more. Your geniality has been infectious, your sense of humor has relieved many a potentially critical situation, your optimism has brushed aside many difficulties, but above all your personality has drawn us to you and inspired affection. And we shall always be eager for your advice and counsel."

PROGRESS OF WORK OF COMMITTEES ON COAL STORAGE

Results of far-reaching economic and social importance are likely to be attained by the nationwide study of the storage of coal now in progress by nearly 100 committees of the Federated American Engineering Societies, it is disclosed in a progress report to the Executive Board of the Federation by Dean Perley F. Walker of the University of Kansas.

Dean Walker, who is directing the field work of the investigation, said that the final report would be ready about January 1, 1924, and would place at the disposal of the nation the most authoritative information obtainable as to the engineering, chemical and economic factors involved in the storage of coal.

More than 500 engineers are actively engaged in making the study under the direction of a main committee headed by W. L. Abbott of Chicago. These engineers have found, it was reported to the Executive Board, that it is necessary to conduct separate investigations to meet peculiar local conditions in various cities and districts. In the Duluth, Minn., district the situation is such as to call for a special report, which is being prepared by W. H. Hoyt and a subcommittee of Minnesota engineers. Similar regional investigations will be begun in the New England states, it was announced, and this method will probably be applied to other areas.

Chicago, Ill., and Worcester, Mass., were cited as examples of a still further localized study to be made in a dozen or more American cities in which community conditions are such as to call for isolated treatment, the findings in each city to be embodied in a special report. The question of central storage systems is being considered for some states, notably Ohio.

An essential reason for the storage of coal study, it was explained, was that mining operations are very intermittent, causing heavy financial risk and a continuous aggravated labor problem to the operators, uncertain annual income and dissatisfaction to labor, high prices to the public, and inordinate seasonal burdens upon the railroads.

F. A. E. S. TO URGE REORGANIZATION OF DEPARTMENT OF INTERIOR

Under the leadership of the Federated American Engineering Societies, the engineering profession will launch a nationwide movement to bring about the adoption by Congress of that portion of the late President Harding's government reorganization program which calls for making over the Department of the Interior.

The Executive Board of the Federation sanctioned this understanding in adopting at its meeting in Rochester, N. Y., October 13, a resolution offered by Philip N. Moore of St. Louis, former chairman of the War Relief Minerals Commission. Fearing that the whole plan of the Government Reorganization Committee will fail of enactment into legislation, the engineers have determined to bend all their efforts toward consolidating the functions of the Interior Department in a division of public works and a division of the public domain.

In the division of public works the engineering functions of the Federal Government, now scattered through many departments and bureaus, would be grouped. Several years ago the engineers of the country organized the National Public Works Department Association, with committees all over the country, for the purpose of abolishing the Interior Department and erecting in its stead a Department of Public Works.

Under the Government Reorganization Committee's scheme, however, the name of the Interior Department would be retained, the engineering activities being coordinated in a separate division. This coordination, the engineers explained, being essentially the result they sought, has been accepted by them, and will be embodied in a bill to be introduced in Congress.

ARTHUR P. DAVIS RETAINED BY THE DEPARTMENT OF STATE

Arthur P. Davis, against whose recent dismissal as Director of the U. S. Reclamation Service the Federated American Engineering Societies made formal protest, has been retained by the State Department as technical adviser in connection with certain claims against the United States by British citizens which are to be tried before the Pecuniary Claims Arbitration Commission in London beginning November 6.

The arbitration of these claims was provided for by a special law of Congress to clear the docket of old pending claims which have not been settled.

Mr. Davis sailed for England October 23 on the *Aquitania* to assist in the preparation of these cases prior to their consideration.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES (SEPT. 1-30, 1923)

Unless otherwise specified, books in this list have been presented by the publishers. The Institute does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

Atomic Structure and Spectral Lines.

By Henry L. Brose. N. Y., E. P. Dutton & Co., 1923. 626 pp., diagrs., 9 x 6 in., cloth. $12.00.

The object of this book is to give a comprehensive account of the new physics of the atom and the meaning of spectral lines, without presenting too great difficulties for the non-academic reader. The present translation is from the thoroughly revised third German edition and embodies the most important recent developments in spectroscopy and atomic physics. An endeavor has been made to render the account vivid and easily intelligible.

Davison's Textile "Blue Book", 1923-24.

N. Y., Davison's Publishing Co., 1923. 1729 pp., maps, 9 x 7 in., cloth. $7.50.

The "Blue Book" is a comprehensive directory of American firms engaged in the textile industries, as manufacturers, dyers, bleachers, brokers, commission merchants or dealers in raw or waste materials. The information on mills includes the location, capacity, number of employes, officials, capitalization,

etc. The directory is classified by products and by location, and a name index is provided. A directory of supply dealers is included.

Dictionary of Applied Physics, vol. 5: Aeronautics; Metallurgy; General Index.

By Sir Richard Glazebrook. Lond., Macmillan & Co., 1923. 592 pp., illus., diagrs., tables, 9 x 6 in., cloth. 63s. (Gift of Macmillan & Co., N. Y.

The concluding volume of this valuable work of reference is divided in two parts, treating of aeronautics and metallurgy respectively. Part one contains long articles on Full Scale Aerodynamical Research, by R. M'K. Wood; Experimental Tests of Strength of Aeroplane Structures, by W. D. Douglas; Theory of Aeroplane Structures, by W. L. Cowley; Doping and Fabrics, by Guy Barr; Performance and Stability of Aircraft, by Leonard Barstow; Airscrews and Helicopters, by Arthur Fage; Experiments on Airships, by J. R. Pannell and R. Jones; Diffusion through Membranes, by Guy Barr; Engines, by G. H. Norman; Model Experiments, by E. F. Relf and H. B. Irving; and Hydrodynamical Theory, by Hermann Glauert.

Among the longer articles in part two are: Typical Alloy Systems, the Equilibrium Diagram and the Relationship of Structure and Physical Constants, by J. L. Haughton; Special Alloys and Aluminum Alloys, by Walter Rosenhain; Aluminum, by Donald Finlayson; Electric Furnaces, by F. A. J. Fitz-Gerald; Laboratory Furnaces, and Refractories, by E. A. Coad-Pryor; Invar and Elinvar, by C. E. Guillaume; Iron-Carbon Alloys, and Defects and Failures of Metals, by D. Hanson; Relations of Strain and Structure, Thermal Study and Thermal and Mechanical Treatment, by Walter Rosenhain; Aggregation and Flow of Solids, by W. D. Haigh; and Special Steels, by W. H. Hatfield. An index to the volume and a general index to the whole work are included.

Electrical Vibration Instruments.

By A. E. Kennelly. N. Y., Macmillan Co., 1923. (Engineering Science Series). 450 pp., illus., diagrs., tables, 9 x 6 in., cloth. $6.50.

Dr. Kennelly's book presents, from an electrical engineering viewpoint, the characteristics of telephone receivers (and of other vibrational instruments) as reciprocating electric motors. It is based on researches carried on at the Massachusetts Institute of Technology and at Harvard University during the past fourteen years. The book is intended as a textbook for students of telephone engineering, and also as a reference book on the receiver for telephone engineers.

Elements of Radio Communication.

By Ellery W. Stone. Second edition. N. Y., D. Van Nostrand Co., 1923. 318 pp., illus., diagrs., 8 x 5 in., cloth. $2.50.

Prepared originally for radio students in the Communication Service of the Navy, this book has proved suitable for use in other schools and for self instruction. The subject is presented physically rather than mathematically, in a manner requiring but little previous knowledge on the part of the reader. This edition has been thoroughly revised and enlarged by the addition of recent developments.

Elements of the Theory of Infinite Processes.

By Lloyd L. Smail. N. Y., McGraw-Hill Book Co., 1923. 339 pp., 8 x 5 in., cloth. $3.50.

Under the title of Infinite Processes, the author has included the subjects of infinite sequences, infinite series, infinite products, infinite continued fractions, infinite determinants and infinite integrals. His work is an introductory textbook, requiring only a knowledge of calculus, intended to give the more important conceptions and propositions of its field in sufficient detail to be intelligible to the beginner, and to serve as an introduction to the study of the special fields. According to the author, no suitable introductory textbook has hitherto been available.

Engineering Kinematics.

By William G. Smith. N. Y., McGraw-Hill Book Co., 1923. 282 pp., illus., diagrs., tables, 9 x 6 in., cloth. $3.00.

In this textbook the author, while giving first consideration to the fundamental principles of motion, its laws, its conversion and its transfer, has also given attention to the application of these principles to the design of agencies for transmission, transportation and production. He thus endeavors to relate the study to actual engineering problems and conditions, so that the student's interest may be awakened by a knowledge of the practical applications of the science.

Factory Management Wastes and how to Prevent Them.

By James F. Whiteford. N. Y., D. Van Nostrand Co., (1920). 220 pp., charts, 9 x 6 in., cloth. $4.00.

Of the work of the average factory, about one-fifth deals with the processing and treatment of materials, and this is usually efficiently done in a well organized way. The remaining four-fifths of the work, dealing with the common things, done day after day by routine, is seldom well organized. It is here that the greatest wastes are to be found.

It is the purpose of this book to discuss these wastes, their causes, detection and remedies. Removal of them will, the author believes, remove some of the prevalent difficulties between employer and employed, manager and managed.

The subjects discussed include works organization and management, production control, machinery, performance records, overtime, cost finding, wages and profit sharing.

"Hutte," des Ingenieurs Taschenbuch. vol. 2, ed. 2.

By Akademischen Verein Hutte, e. v. in Berlin. Berlin, Wilhelm Ernst & Sohn, 1923. 1288 pp., illus., tables, 7 x 5 in., cloth. $2.00.

The second volume of this new edition covers the important subjects of Prime Movers, Measurements, Machinery, Shipbuilding and Marine Engines, Automobile Construction, Lighting and Electrical Engineering. It has been partly rewritten and partly revised, over 200 pages having been added. The principal additions have to do with Boilers, Engines, Steam Turbines, Internal Combustion Engines, Hoisting Machinery, and Electricity. Each section is the work of a group of specialists.

Mechanics of Machinery; Mechanism.

By Robert C. H. Heck. N. Y., & Lond., McGraw-Hill Book Co., 1923. 508 pp., diagrs., 9 x 6 in., cloth. $5.00.

Contents:—Elements and principles of machines. Machinery for uniform motion. Intermittent motion. Gear trains for speed variation. Cyclic and differential trains. Linkage mechanisms and movements. Form action and production of gear teeth. Gear teeth in space. Index.

The purpose of this work on the mechanics of machines is to cover the whole field of motions and forces in machines, in a manner suitable for study and teaching and as a related and consistent whole instead of as scattered, isolated branches.

The present volume treats chiefly of mechanism. The material presented is arranged according to the problems in mechanism or mechanics which it presents, rather than according to kinds of machines. The ground is covered with sufficient completeness to make the book a useful reference treatise as well as a textbook.

Metals and Metallic Compounds.

By Ulick R. Evans. N. Y., Longmans, Green & Co., 1923. Vols. 3 & 4, illus., 9 x 6 in., cloth. Vol. 3, $4.75; Vol. 4, $6.00.

In this book the author has taken advantage of modern research in metallography, crystallography, electrochemistry, etc., and has approached the subject of metals in a new spirit. He avoids catalogs of compounds and empirical accounts of metallurgical processes; and attempts to correlate cause and effect, and to introduce such theoretical views as will serve to connect the known facts in an ordered sequence, in readable form.

Volumes 3 and 4 treat of the more important industrial metals, iron, nickel, platinum, copper, silver, gold, zinc, mercury, tin, lead, etc. The pure chemistry of each metal and its compounds is first discussed; then its terrestrial occurrence; and finally its technical preparation for use. Numerous references to the literature are given.

Mineral Valuation.

By Henry Louis. Lond., Charles Griffin & Co., Phila., J. B. Lippincott Co., 1923. 281 pp., 9 x 6 in., cloth. 15s. (Gift of J. B. Lippincott Co.)

The object of the present work is to lay before mining engineers and others interested the views of its author upon the principles underlying mineral valuation, in the form into which they have crystallized during the course of many years of experience in the practise of this branch of the mining profession. The author is concerned to bring out in the first instance the cardinal fact that all mineral valuations must be based upon an estimate of probabilities, never of certainties; a consideration too often overlooked by those interested in the subject. He has developed this theme to show how the mathematical conceptions of probability can be applied to mining valuations, so as to give a more definite meaning to them.

The actuarial formulas are presented in a form for logarithmic computation. They are sufficient, Dr. Louis believes, to

answer all purposes. He also discusses at length the collection of the data necessary for the calculations.

PRACTICAL APPLICATIONS OF X-RAYS.

By G. W. C. Kaye. N. Y., E. P. Dutton & Co., 1923. 135 pp., illus., diagrs., tables, 9 x 6 in., cloth. $5.00.

In this book the author, who is head of the radiology department of the National Physical Laboratory, confines himself to the practical uses of X-rays in science and industry. A brief introductory chapter on the nature and generation of X-rays is followed by chapters on X-ray bulbs, high-potential generators and methods for the measurement of X-rays. Chapter five discusses the medical applications of X-rays in diagnosis and the treatment of disease. Chapter six calls attention to industrial applications, such as the examination of metals for flaws, of explosives and ammunition, of timber, aircraft, welds, rubber and glass, the investigation of old paintings, etc.

RADIO PHONE RECEIVING.

By Erich Hausmann & others. N. Y., D. Van Nostrand Co., 1922. 183 pp., illus., diagrs., 8 x 5 in., cloth. $1.50.

This book, by a group of experienced engineers, is intended for the general reader who wishes an authoritative, simple account of the methods and apparatus used for the reception of radio phone speech and music. The book will be useful to novices and amateurs, as it avoids complicated descriptions and mathematics. Numerous practical hints and answers to questions that often arise are given.

PHYSICS IN INDUSTRY, vol. 1.

By Archibald Barr, Sir James A. Ewing & Clifford C. Paterson. Lond., Henry Frowde, & Hodder & Stoughton, 1923. (Oxford Technical Publications). 59 pp., 10 x 6 in., boards. $,85. (Gift of Oxford University Press. American Branch).

The British Institute of Physics has established a series of lectures on the part played by physics in various industries. These lectures are intended to inform those interested in the application of science to the industries and to guide and help students of physics who intend to devote themselves to industrial research.

The three lectures here presented, the first of the series, were delivered during 1922. Dr. Barr pays especial attention to the applications of physical research in mechanical engineering; Sir James Alfred Ewing speaks on the "Physicist in Engineering Practise;" and Mr. Paterson on the "Physicist in Electrical Engineering."

STEEL THERMAL TREATMENT.

By John W. Urquhart. N. Y., D. Van Nostrand Co., 1922. 336 pp., illus., tables, 9 x 6 in., cloth. $8.00.

Having been engaged for many years in the production of machinery and tools, the author has been under the necessity of putting to practical use all the recently introduced processes for the heat treatment of steel. This book describes the apparatus used for heat treatment, the processes and their adaptation to various purposes. The physical and chemical phenomena that occur are explained and an endeavor is made to co-ordinate the work of the laboratory and the factory.

ULTRAVIOLET RADIATION.

By M. Luckiesh. N. Y., D. Van Nostrand Co., 1922. 258 pp., illus., tables, 9 x 6 in., cloth. $3.50.

In this book Mr. Luckiesh presents authentic data of such scope as to be useful to chemists, physicists, engineers and others interested in ultraviolet radiation, its properties, production and radiation. The book is a useful summary of the facts that have been ascertained by experiment and is provided with many bibliographical references.

TREATISE ON CHEMISTRY, vol. 2; The Metals. 6th edition.

By H. E. Roscoe & C. Schorlemmer. Lond., Macmillan & Co., 1923. 1565 pp., illus., diagrs., 9 x 6 in., cloth. $15.00. (Gift of Macmillan Co., N. Y.).

The sixth edition of this well-known work has been thoroughly revised by a group of writers under the editorship of B. Mouat Jones. Much new knowledge of the chemistry of the metals and their compounds has been obtained during the ten years that have elapsed since the fifth edition of this treatise appeared, and an endeavor has been made to incorporate the most important part of this new material while bringing the rest of the volume up to date. The general character of the work, as a systematic account of the metals and their compounds, has been retained.

Past Section and Branch Meetings

PAST SECTION MEETINGS

Akron.—September 22, 1923, luncheon at Portage Hotel. Future plans were discussed. After lunch the party, numbering 23, visited the North High Street substation of the Nothern Ohio Traction and Light Company.

Cincinnati.—September 13, 1923, Assembly Hall, Union Gas and Electric Company. Subject: "The Manufacture of Porcelain." Speaker: Mr. F. H. Riddle, Director of Research, Champion Porcelain Company, Detroit. Attendance 65.

Connecticut.—October 4, 1923, Dunham Laboratory of Electrical Engineering, New Haven. Joint meeting with the Yale University Branch. Subject: "Supervisory Control for Power Systems." The General Electric Company, Westinghouse Electric & Manufacturing Company, and Western Electric Company had installed apparatus to demonstrate the operation of the control equipment and of the visible and audible response of the mechanisms. The equipment was energized and was resorted to by the speakers in their talks. It proved to be a convincing portion of the program and much interest in the apparatus was manifested by the audience. Mr. C. E. Stewart described the General Electric Company's equipment, and Mr. F. Zogbaum explained the functioning of the Western Electric Company's equipment, which is coordinated with that of the General Electric Company. Mr. R. J. Wensley, representative of the Westinghouse Electric & Manufacturing Company described that company's type of equipment. Attendance 110.

Denver.—September 21, 1923, Adams Hotel. Subject: "The Establishment of Telephone Communication Between the United States and Cuba" (illustrated by lantern slides). Speaker: Mr. H. S. Osborne, Transmission Engineer, American Telephone and Telegraph Company. Attendance 50.

Erie.—September 19, 1923, Academy High School. Subject: "The General Theory of Gaseous and Solid Dielectrics." Speaker: Professor V. Karapetoff, of Cornell University. Professor Karapetoff gave a piano recital after the technical session. Attendance 210.

Fort Wayne.—September 27, 1923, General Electric Company's Recreational Building. Business and social meeting. Those present were entertained by motion pictures and vocal and instrumental music. Refreshments were served. Attendance 66.

Minnesota.—September 24, 1923, University of Minnesota. Subject: "Electric Farm Service." Speaker: Mr. S. B. Hood, Superintendent of Distribution, Northern States Power Company. Attendance 50.

New York Section.—The first Section meeting for the year 1923-24 was held at Institute headquarters, New York, on the evening of Wednesday, October 24. Chairman L. F. Morehouse presided. After opening the meeting he called on Secretary E. B. Meyer to outline the meeting plans for the year as arranged by the Program Committee of the Section. In closing Mr. Meyer called upon the membership for suggestions in connection with developing an interesting list of meetings. The Chairman then outlined the history of the establishment of the Federated American Engineering Societies and called upon L. W. Wallace, the Executive Secretary of the F. A. E. S. to speak. Mr. Wallace in a very interesting talk reviewed the accomplish-

ments of the Federation and showed how intimately concerned its work was with the welfare of engineers and of the nation. Mr. Wallace's talk was followed by five reels of "Motion Pictures of the Invisible." Mr. Handy who is associated with the development of this type of picture pointed out the salient points of interest during the running of the reels. The smokers present were invited to indulge as the guests of the Section. Attendance about 260.

Pittsburgh.—September 18, 1923, Reception Room, William Penn Hotel. Subject: "Water-Wheeled Generators and Synchronous Consensers for Long Transmission Lines" (paper presented at Pacific Coast Convention, A. I. E. E., Del Monte, Cal., Oct. 5-7). Speaker: Mr. M. W. Smith, Designing Engineer, Westinghouse Electric and Manufacturing Company, Attendance 160.

October 9, 1923. Special arrangements were made with the Pennsylvania Railroad to transport the Institute members and their guests to the North Trafford Laboratory of the Westinghouse Electric and Manufacturing Company. The meeting was opened by the presentation of two papers: "A Million Volt Testing Transformer Set" by Mr. F. J. Vogel, Transformer Engineer, Westinghouse Electric and Manufacturing Company; "High Voltage Measurement" by Mr. D. F. Miner, Material and Process Engineer, Westinghouse Electric and Manufacturing Company. Following the papers a demonstration of high-voltage phenomena was made including the maintaining of an arc over a distance of some 40 feet, the behavior of horn gaps under high-voltage flashover conditions and wet and dry flashovers on a column of insulators utilizing voltages up to 800,000 volts. Attendance 605.

Providence.—October 5, 1923, Rooms of Providence Engineering Society. Subject: "Present Views of the Structure of the Atom and the Origin of Light." Speaker: Dr. Saul Dushman, of the General Electric Company. By means of an electrically operated model and numerous lantern slides Dr. Dushman discussed the present views on the structure of the atom and the origin of light, the nature of the electron, number and arrangement of electrons in the atom, structure of the nucleus of the atom, and the relation between light spectre and the arrangement of electrons in the atom. At the conclusion of the talk an interesting discussion was held. Professor James W. McBain of the University of Bristol, England, was present and gave some interesting comments on the talk during the discussion period. Attendance 110.

Rochester.—October 5, 1923. Inspection trip to the mine and plant of the Sterling Salt Company, at Cuylerville, which is well equipped with electric hoists, electric locomotives, etc. The members inspected both the electrical and mechanical facilities, and methods were explained by Mr. M. H. Curley, General Manager. Following this the party stopped at the plant of the Retsof Mining Company, where electrical equipment has recently been installed. Attendance 29.

San Francisco.—September 24, 1923, Native Sons Hall. Subject: "Engineering Problems of the Electric Power Industry." Speaker: Dr. Charles P. Steinmetz. Attendance at call of meeting 1580.

Seattle.—September 19, 1923, The College Club. Annual Banquet. After a short business meeting Chairman Lund introduced Professor W. A. Russel, C. E. M. E., who had selected as his subject: "The Engineer's Latest Job." Attendance 48.

Schenectady.—October 5, 1923, Edison Club Hall. Smoker. Attendance 150.

Toronto.—October 5, 1923, Engineer's Club. Social and get-together meeting. Attendance 76.

Vancouver.—September 15, 1923. Excursion to the Stave Falls Power Plant of the British Columbia Electric Railway Company. A thorough inspection was made of the entire plant, including extensive construction works in progress. Attendance 35.

PAST BRANCH MEETINGS

University of Alabama.—September 25, 1923. Business meeting. Attendance 8.

University of California.—September 12, 1923. Subject: "Large Water Wheels and Reaction Turbines." Speaker: Mr. Ross L. Mahon, Sales Engineer for Pelton Water Wheel Co. Attendance 48.

September 24, 1923. Subject: "Engineering Problems in the Electrical Industry." Speaker: Dr. Charles P. Steinmetz.

September 29, 1923. Inspection trip to Pelton Water Wheel Company of San Francisco. Attendance 15.

University of Cincinnati.—September 20, 1923. Election of officers as follows: Chairman, J. F. Morrissey; Vice-Chairman, A. E. Cavagnaro; Treasurer, Ralph Fowler, Sec. X, C. T. Button, Sec. XX; Secretary, Professor C. B. Hoffmann. Brief talks as follows: "Advantages of Membership" by Professor A. M. Wilson; "What the University of Cincinnati Branch of the A. I. E. E. Aims at this Year" by Professor C. B. Hoffmann; "Get Into the Institute" by Professor W. C. Osterbrock. Attendance 98.

September 27, 1923. Joint meeting with the Chemical Engineering Society for Sec. X. Moving picture "Mexico and Its Oils." Attendance 192.

October 4, 1923. Meeting of Sec. XX with the Chemical Engineering Society. Moving picture "Mexico and Its Oils." Attendance 177.

University of Colorado.—October 4, 1923. Talks on the aims and benefits of the Institute and related activities were given by Dean Evans, Professor DuVall, Professor Coover, Mr. Hull and Mr. Easton. Attendance 80.

University of Denver.—September 25, 1923. Election of officers as follows: Chairman, Charley G. Diller; Vice-Chairman, Gail C. Shores; Secretary-Treasurer, Ray Hoover. Attendance 13.

State University of Iowa.—October 1, 1923. Election of officers as follows: Chairman, P. A. Stover; Vice-Chairman, G. C. K. Johnson; Secretary, J. M. Dean. The rest of the session was occupied in showing a cinema of the process of manufacture of watt-hour meters. Attendance 50.

University of Kansas.—September 27, 1923. Introduction of the teaching personnel of the Electrical Department to the new students. Discussion of the aims of the Branch for the school year. Talk by Professor Shaad on the relation of the Institute to those enrolled in electrical engineering courses. Refreshments were served. Attendance 53.

Kansas State Agricultural College.—September 17, 1923. Talks as follows: "Utah Power and Light Company" (summer work) by Mr. B. Bivens; "Chicago, Milwaukee and St. Paul Railway" (employment in Signal Department on the electrified section on the Continental Divide in Montana) by Mr. W. K. Lockhart. Attendance 55.

Lafayette College.—September 22, 1923. Election of officers for the ensuing year as follows: Chairman, William Welsh; Secretary, John B. Powell. Professor King, head of the electrical engineering department, gave an interesting talk on his summer work with the Bell Telephone Company, Philadelphia Attendance 21.

Lehigh University.—October 4, 1923. Talks by Professors. Esty, Schealer, Seyfret and Beaver to stimulate interest in the society and to point out the benefits derived therefrom. Refreshments were served. Attendance 81.

Marquette University.—September 18, 1923. Smoker. Mr. Frazer Jeffrey, of the Allis-Chalmers Company, and Mr. W. H. Costello addressed the meeting on the advantages of being a member of the Institute. Attendance 27.

University of Nebraska.—October 4, 1923. This meeting was for the purpose of acquainting the students with the aims, purposes and oganization of the A. I. E. E. Dean O. J. Ferguson discussed the national organization, and Professor O. E. Edison discussed the organization of the local Branch. Attendance 57.

University of North Carolina.—October 4, 1923. Interesting talks on the Carolina Engineering School were given by faculty members, and plans were laid for a successful season of the Branch. Attendance 42.

Northeastern University.—September 24, 1923. Organization meeting and election of officers as follows: Chairman, L. F. Hubby, Vice-Chairman, K. M. Barney; Secretary-Treasurer, E. G. Crockett; Assistant Secretary, M. G. Pierce.

University of Notre Dame.—September 24, 1923. Election of officers as follows: Chairman, Frank Egan; Vice-Chairman, Edward Sullivan; Secretary, Kenneth Faiver; Treasurer, Hubert Hersam. Dr. J. A. Caparo, head of electrical engineering department, gave a short talk on technical education and the need of broadening influences such as are afforded by membership in the A. I. E. E. Attendance 30.

October 1, 1923. Business meeting and appointment of committees. Dr. J. A. Caparo gave a talk on the value of a technical education, and discussed the elusive topics of perpetual motion and the impossible geometric solution of certain problems. Attendance 62.

Ohio Northern University.—October 5, 1923. Subject: "Advantage of an Electrified Railroad Over Steam Railroad." Speaker: Mr. Frazine. Attendance 32.

Pennsylvania State College.—October 5, 1923. Election of officers as follows: Chairman, H. O. Alexander; Vice-Chairman, J. L. Garrett; Treasurer, W. H. McLaughlin; Secretary, Leon Lentz, Jr.; Sergeant-at-arms, G. W. Lehr. Professors Markle and Doggett gave interesting talks on the opportunities the Branch affords in aiding the student to secure a broader knowledge in the field of electrical engineering. Attendance 26.

Purdue University.—October 2, 1923. Talks as follows: "Organization of the A. I. E. E." by Professor C. F. Harding; "Local Membership in the Organization" by Professor A. N. Topping; "Aims of the Organization" by Professor L. D. Rowell. Refreshments were served. Attendance 156.

Syracuse University.—September 24, 1923. Election of officers as follows: Chairman, Edward J. Agnew; Secretary, John G. Hummel. Attendance 20.

West Virginia University.—October 1, 1923. Election of officers as follows: Chairman, O. A. Brown; Vice-Chairman, P. F. Hill; Secretary, James Copley; Treasurer, D. S. Raush; Publicity Agent, M. C. Holmes. Attendance 33.

PERSONAL MENTION

Bernard Otting has left the employ of the Cincinnati Ball Crank Company and is now with the Willy Wray Electric Company, Cincinnati, Ohio.

Walter J. Rey, formerly with the Chicago, Milwaukee & St. Paul Ry. Co., is now connected with the Allis Chalmers Mfg. Co., in the Electrical Department.

C. B. Wright is now employed with the Kansas Gas & Electric Company, Wichita, Kansas. He was formerly with the Duquesne Light Company of Pittsburgh, Pa

R. B. Chillas, Jr. has resigned from the National Aniline & Chemical Co., Buffalo, N. Y. and is now associated with the Atlantic Refining Company, Philadelphia, Pa.

A. A. Pehrson has resigned from the employ of the Western Electric Company, and returned to business as President of the A. A. Pehrson Electric Corporation, 103 Park Ave., New York City.

Otto M. Rau, of Philadelphia, has recently been appointed in a consulting capacity on the staff of the Power Survey which has been begun in Pennsylvania at the instance of Governor Pinchot.

P. M. Duncan has severed his connection with the Western Electric Company, Hawthorne plant, to accept a position as a Development Engineer with the Allen-Bradley Company, Milwaukee, Wis.

Leland B. Bonnett, has severed his connection with the General Electric Company, New York City, to become associated with the Brooklyn Edison Company, Brooklyn, N. Y., as Inside Plant Engineer.

William N. Fenninger, who recently resigned from his position of Expediting Engineer with the Brooklyn Edison Co., is now Supervisor of Electrical Courses at the Mechanics Institute, Rochester, N. Y.

E. C. Morse, formerly President, Foreign Trade & Supply Company, New York City, has recently resigned to become Vice President in Charge of Sales, of the Triumph Electric Company, Oakley, Cincinnati, Ohio.

W. A. Murray has resigned as Instructor in Electrical Engineering at the University of Idaho, to accept a position as Assistant Professor of Electrical Engineering at Montana State College, Bozeman, Montana.

Leroy A. Nettleton has become connected with the Brooklyn Edison Company in the capacity of an inspector in the Electrical Engineering Dept. Previously he was with the Westinghouse Electric & Mfg. Co.

Sidney K. Wolf has become connected with the Sheffield Scientific School, of Yale University, as an instructor in Electrical Engineering. He has recently resigned from the employ of the Westinghouse Electric & Mfg. Co.

G. H. Wirth has accepted a position as Electrical Engineer with the Right and Left Tool Holder Company, Philadelphia, Pa. He was previously in U. S. Government service as Chief Shop Instructor in Philadelphia Pa.

Walter R. Roxbury has resigned from the Engineering Dept of the New York Edison Company, to become an Engineer in Charge of Public Utilities Division, Power Plant Equipment, of the McIntire Corporation, Newark, N. J.

Frank H. Parker, who was formerly Chief Engineer, Hotel Belleclaire, for the Engineering Supervision Co., New York City, is now associated with Cross & Brown Co., New York City, as Superintendent, Heating and Power Plants.

D. A. Ennis, formerly Assistant General Foreman of the Testing Department of the General Electric Co. at Schenectady, N. Y., has accepted a position as Electrical Engineer for the Glens Falls Portland Cement Co., at Glens Falls, N. Y.

Wm. J. Miller has resigned as Professor of Electrical Engineering at the Oklahoma A. & M. College, and has accepted a position as Research Engineer with the Engineering Experiment Station of the University of Arkansas, Fayetteville, Ark.

David O. Woodbury resigned in August as Assistant to the Transmission Engineer, Pacific Telephone & Telegraph Company, and has recently become associated with the American Appliance Co., Cambridge Mass., as Research Engineer.

C. P. Tolman has resigned as Chief Engineer and Chairman of the Manufacturing Committee of the National Lead Company, which position he had held for sixteen years, to open an office for general consulting practise, at 111 Broadway, New York City. He continues his connection with the National Lead Company as a consultant.

A. T. Ward, who has been associated for nearly five years with the Union Carbide & Carbon Corporation of New York, resigned on October 1st to engage in business for himself, operating under the name of the Acme Coal Mining Sales Corporation, 20 Broad St., New York City.

H. R. Whiting has resigned his position as Superintendent of Steam Plant & Substations with the Porto Rico Railway, Light & Power Co., San Juan, P. R. and has accepted the position of Superintendent Engineer with the Compania Electrica de Santo Domingo, Santo Domingo, R. D.

Clark A. Terry has recently severed his connection with the General Electric Company as Construction Engineer at Schenectady, N. Y., to become Superintendent of the Sherman Island Hydro-Electric Development Company of the International Paper Company at Glens Falls, N. Y.

Guy E. Tripp, Chairman of the Board and Loyall A. Osborne, President of the Westinghouse International Company, left for Japan on October 4th. They sailed from San Francisco on October 10th in the *S. S. Shinyo Maru*, and will visit Shanghai, Hongkong, Pekin and the Philippines before returning home.

Edward Woodbury has recently been appointed Electrical Engineer of the Merced Irrigation District on power house design and construction for the consulting engineers of the project. Previous to this, he was Superintendent in charge of the installation of the hydraulic and electrical features of the Pit River power house.

A. L. Rohrer, Superintendent of Light, Heat and Power at the Schenectady works of the General Electric Company, has retired after thirty-nine and a half years service with that company, and is succeeded by C. A. Clark, who has been assistant superintendent since the department was organized in 1917. Mr. Rohrer will remain with the company in an advisory capacity.

Obituary

Frederick C. Bates, a Member of the A. I. E. E. died on October 2, 1923, at his home in Brooklyn, N. Y., after a protracted illness. He was born in Danielson, Conn., in 1867. In 1887 he entered the employ of the Thomson-Houston Company, at Lynn, Mass. and was sent to Berlin in 1894 to supervise electrical installations with the Allgemeine Elektrictats-Gesellschaft. Upon his return, in 1896 he became connected with the New York office of his company, and he was made manager of the lighting department. For twenty-seven years thereafter Mr. Bates was employed by the General Electric Company, acting for many years as manager of the Lighting department in the New York office. He was vice president of the Orange County Public Service Corporation and an officer in its affiliated companies. He was a member of the Machinery Club and the Engineer Club of New York City.

John Grant, Chief Electrician for the Utica Willowvale Bleaching Company, died as the result of electric shock at Chadwick, N. Y., July 11, 1923. He was born in Ireland in 1889. After serving an apprenticeship with the B & C Electric Company at Utica, N. Y., he was connected with that company as foreman of electric construction. For several years he was with the National Knitting Company at Milwaukee, Wis., from which he resigned to accept the position which he held at the time of his death. He became an Associate of the Institute in 1921.

Addresses Wanted

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N.Y.

All members are urged to notify the Institute headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—George G. Chow, c/o S. K. Lau, 351A Weihaiwei Road, Shanghai, China.
2.—C. C. Cobb, 209 W. 2nd St., Oklahoma City, Okla.
3.—Thomas R. Cummins, Autorite Products Co., Ontario, Calif.
4.—Charles E. Grant, Christie St. Hospital, Toronto, Ont., Can.
5.—John F. Greene, 5107 Cullom Ave., Chicago, Ill.
6.—Donald T. Mason, 91 Wick Place, Youngstown, Ohio.
7.—Milan S. Mitrovitch, Box 254, Roseville, Placer Co., Calif.
8.—Cyrus A. Perkins, 139 Dundas St., E., Toronto, Ont., Can.
9.—Otto Pramm, Hydro-Elec. Pr. Comm., Toronto, Ont.
10.—Oscar A. Schlesinger, 64 Fairview Ave., Piedmont, Calif.
11.—E. D. Simpson, 4104 Agua Vista St., Oakland, Calif.
12.—E. Slager, 4149-51 East 79th St., Cleveland, Ohio.

Employment Service

The Engineering Societies Employment Service is conducted by the national societies of Civil, Mining, Mechanical, and Electrical Engineers as a cooperative bureau available to their membership, and maintained by the joint contributions of the societies and their individual members who are directly benefited.

MEN AVAILABLE.—Under this heading brief announcements will be published without charge to the members. These announcements will not be repeated, except upon request received after an interval of three months, during which period names and records will remain in the active files of the bureau. Notice for the JOURNAL should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City.*** *Such notices will not be acknowledged by personal letter, but if received prior to the 16th of the month will usually appear in the issue of the following month.*

OPPORTUNITIES.—A bulletin of engineering positions available will be published and will be available to members of the societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the societies in the financing of the work by nominal contributions. It is believed that a successful service can be developed if these contributions average $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum. temporary positions (of one month or less), three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will, it is hoped, be sufficient to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled, will not be forwarded.

MEN AVAILABLE

ELECTRICAL ENGINEER '22 and B. S. '21 desires to change his position. Has had 21 months' experience, of this period, 9 months in radio and balance in general electrical engineering. During past year has been doing designing, testing, drafting and supervision in an electrical instrument manufacturing shop. Would like to connect with a responsible concern in New York City or vicinity. Starting salary $2000. E-4520.

GRADUATE M. E., E. E. 26 years, wishes to connect with an industrial concern, preferably in the metal trades to learn the manufacturing end. Has 3 years' experience in the field as tester of electrical and mechanical machinery and 1 year as schedule planning engineer. Has taken course of factory engineering and management at N. Y. U. Location N. Y. E-4521.

ELECTRICAL ENGINEER. Technical graduate. Age 24. Desires connection with some good engineering firm. Four years' experience in maintenance and construction of transmission lines and general public utility work. Also six months commercial experience. Prefer Eastern Pa., but will consider good proposition anywhere. E-4522.

ELECTRICAL ENGINEER. Technical graduate, G. E. test control engineering and anthracite mining experience in all phases of electrical work wishes position with company tha

will lead to other than operating and maintenance work, preferably the commercial end of the game. E-4523.

ELECTRICAL ENGINEER. Age 35, technical graduate desires position with anthracite or bituminous coal producing company. Fourteen years' experience including two years' of G. E. test and eight years with large anthracite producer. Services now available. E-4524.

GRADUATE ELECTRICAL ENGINEER. Eight years' engineering experience with power and light utilities, desires position with utility company with chance for advancement, especially work which will develop into executive or managing position. E-4525.

ELECTRICAL ENGINEER. Technical graduate, 1912. Two years' test and nine years' public utility experience, commercial engineering, construction and maintenances of power houses, substations and transmission lines. Desires responsible position with possibility of ultimate interest in engineering or operating company. Immediate partnership with successful engineer considered. References given. E-4526.

ELECTRICAL ENGINEER. Technical graduate married, age 34. Eight years' experience in design, engineering and construction of power plants, substations and distribution systems, with largest engineering, industrial and public utility corporations. Available 30 days after agreement. References furnished upon request. E-4527.

GRADUATE MECHANICAL ENGINEER 14 years' experience; public utility operation, power and substations, line work, inspecting, supervision; designing, drafting, layout, industrial plant, chemical apparatus, marine work, power house, fire protection, desires position with engineering concern, utility or industrial plant. New York City or vicinity. E-4528.

SALES ENGINEER. Highest reputation' wishes to represent manufacturer in Washington' Oregon, Idaho, Montana and British Columbia' commission basis only. Have had 17 years' sales and engineering experience, 6 years' sales engineer for one of the largest electrical manufacturers in Canada. Will consider only high grade guaranteed products, electrical machinery, power plant and industrial, transmission line and sub-station equipment, radio apparatus, lighting and household appliances. Now established in Seattle, have thorough acquaintance with territory. E-4529.

ELECTRICAL ENGINEER GRADUATE, also M. Sc. degree, specializing in radio and communication engineering. G. E. test course, three years' transformer and designing experience together with manufacturing supervision. Age 30; married. Manufacturing, process or research connection preferred. Available at once. E-4530.

FIELD ENGINEER, thoroughly experienced in estimating, design, supervision and erection of heating, ventilating, plumbing, power piping and automatic sprinkler systems; experience on large projects of the better kind. Have just completed equipment in 24 story office building in large eastern city. Location immaterial, although eastern U. S. preferred. Permanent connection desired with possibilities. Assoc. A. I. E. E. & A. S. H. & V. E. Still employed, but desires change. E-4531.

I AIM TO SELL, I would like to hear from a reliable firm, preferably electrical, which will train and develop me into a salesman. I am a graduate electrical engineer, 22 years old and have had 16 months experience in the distribution and power sales department of large public utility company. Location, New York or vicinity. E-4532.

ELECTRICAL ENGINEER, technical graduate and executive, now employed, wishes to make change. Assoc. A. I. E. E. Seven years' experience in railroad electrical work. Desire position with manufacturer of railroad electrical equipment or automatic machinery. Will consider opening in similar work. E-4533.

GRADUATE ELECTRICAL ENGINEER, 14 years' experience in sales, sales-engineering, purchasing and executive management. Capable of managing commercial department of public utilities; electrical contracting and supply business; purchasing-agent engineer of business executive of industrial company. Age 38; married. Prefer location in eastern or southern United States. Services available on short notice. E-4534.

ELECTRICAL ENGINEER, age 37; married. Familiar with operation and maintenance steam electric stations and boiler-houses. Six years installation work and later district engineer large electrical manufacturer. Wide experience industrial applications. Steam economy work large paper manufacturer. Graduate mechanical engineer. Desires connection power company, engineering firm. E-4535.

ELECTRICAL ENGINEER, age 27, single. College graduate with B. S. degree, university extension division graduate in power plant. Power plant experience two years, and machinist trade six years. Desires position either as a service engineer or in testing department. Available at anytime. E-4536.

ELECTRICAL ENGINEER, over 30, long experience in power production and wire communication. Last 6 years work in radio practise and electrical research; experienced executive. Will go anywhere. Responsible position only considered. E-4537.

1919 GRADUATE of the E. E. course at Cooper Union Institute, degree of B. S., age 26. Has had 2 years of d-c. machinery testing, and five years' experience as electrician on electric light and power installation. Would like a position with electric light and power or mining concern. Main consideration chance for experience. Location immaterial. E-4538.

MECHANICAL & ELECTRICAL ENGINEERING EXECUTIVE, having recently completed rehabilitation of large electric railway system, including boiler house, turbine and engine rooms, substations and lines as resident consulting and construction engineer now available. Seven years' commercial, consulting, construction and export experience in executive capacity, preceded by six years with Westinghouse as foreman of test and commercial engineer. Cornell graduate, Member both A. S. M. E. and A. I. E. E. Passed first in recent examination by Civil Service Commission for Mechanical and Electrical Engineers at $5000. E-4539.

ELECTRICAL ENGINEER EXECUTIVE, broad experience manufacturing field. Expert development and design of small apparatus manufacturing methods, quantity production, standardization materials and parts, planning, commercial manufacture, factory organization and routine, plant and department layouts. Desires connection with manufacturing concern, consulting or industrial engineer operating in manufacturing field. American, Christian. E-4540.

GRADUATE ELECTRICAL ENGINEER, 25 years' experience in design of electrical appliances, switchboards and control; plant operation and installation; industrial and marine power applications. Desire change to field of broader responsibilities. Have initiative, excellent habits and health. Best of references as to mechanical, electrical and executive ability and experience. Location immaterial. E-4541.

ENGINEERING EXECUTIVE, technical graduate, eight years with leading engineering companies, twelve in own business as consulting and constructing engineer, seeks employment. Major experience in locating, designing, constructing, and operating steam and hydroelectric plants, public service properties, industrial power systems, etc. Member A. S. M. E. Fellow A. I. E. E., licensed professional engineer, New York State. E-4542.

GRADUATE ENGINEER, 26 years old; 2 years' G. E. Test experience and 2 years manufacturing experience along the lines of efficiency work involving time studies, planning and despatching in a large manufacturing plant. Desires a position with eastern manufacturing concern with chance to work up into the organization. At present employed, but desires change due to expiration of present contract. Available in 30 days. E-4543.

ELECTRICAL ENGINEER, M. I. T., 1923. Desires connection with engineering firm or public utility company in New York City or vicinity. Excellent mathematician, resourceful, initiative. Good knowledge of accounting and allied business subjects. Salary second consideration. Employed at present, but available on short notice. E-4544.

TECHNICAL GRADUATE, age 25, single. Graduate student course Westinghouse Co., 1½ years test and 3 years field engineering with same company. Desires position with public utility or assistant to engineering executive in Boston or vicinity. E-4545.

GRADUATE ELECTRICAL AND MECHANICAL ENGINEER, technical and university training from France and Switzerland. Age 34; single; 8 years' varied experience in Europe and United States, designer of power stations and substations, foreman of electric railway repair shop and estimating engineer. Desires a position as power station designer. Location immaterial. E-4546.

RECENT GRADUATE B. S., in electrical engineering with some experience in steam electric power plant testing; small motor and storage battery production besides some training in illuminating engineering design and estimating. Desires a permanent position with some central station or manufacturing concern where a hard worker is appreciated. Age 26 and single. Residence Ohio. Location immaterial. Available at once. E-4547.

ELECTRICAL SUPERINTENDENT OR CHIEF ELECTRICIAN, have had over twenty years' practical experience in construction and maintenance, of power and industrial plants and substations, both a-c. and d-c. current. A current up to 22,000 volts. First class technical knowledge of both lines. Have had charge of plants for past twelve years, and am at present employed, but can leave on a fair notice. Can furnish recommendation from my present employer and others. Will accept any reasonable offer in eastern, middle or southern States. Salary at present $250. per month. Assoc. A. I. E. E. E-4548.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED OCTOBER 26, 1923

ABRAHAM, YEHUDA, Drafting, G. & E. Electric Specialties Co., 7440 S. Chicago Ave., Chicago, Ill.

AMES, IRVING MORRIS, 504 So. 11th St., Newark, N. J.

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ANDREN, AUGUST, 177 Park Place, Brooklyn, N. Y.

ARCEO, ANTONIO, Superintendent of Distribution, The Mexican Light & Power Co., Ltd., 20 Gante St., Mexico City, Mex.

*BAILEY, ROBERT COOPER, Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

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BENNETT, DUDLEY EARL, Asst. to Supervisor, Electrical Inspection, Gray & Davis, Inc., Cambridge, Mass.

BINGHAM, JOHN MERTON, Asst. Engineer, Horowhenua Electric Power Board, Levin; for mail, Hamilton, N. Z.

BODDY, LEONARD, Research Chemist, Laboratory, Erie Works, General Electric Co., Erie, Pa.

BOELSTRELI, ARTHUR A., Designing Engineer, Electric Bond & Share Co., 65 Broadway, New York, N. Y.; res., West Hoboken, N. J.

BROWN, WILLIAM AUGUSTUS R., Senior Shift Engineer, Radio Corp. of America, Port Jefferson, N. Y.

BUNKER, FRANK C., Electrical Engineer, General Electric Co., Schenectady, N. Y.

*BURNHAM, GUY LLEWELLYN, Equipment Engineer, Wisconsin Telephone Co., Milwaukee, Wis.

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CHESHIRE, ALFRED AUSTIN, Electrical Engineer, Sumner Borough Council, Christchurch; res., Truro St., Sumner, Christchurch, N. Z.

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NAEF, OTTO, Electrical Engineer, Scintilla Magneto Co., 225 West 57th St., New York; res., Ithaca, N. Y.
NASH, RICHARD LELAND, Electrician, Potomac Electric Power Co., 14th & C Sts., N. W., Washington, D. C.
NAUGLE, JOHN FRANK, Draftsman and Designer, D. P. Robinson & Co., Inc., 125 E. 46th St., New York; res., Brooklyn, N. Y.
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O'LEARY, PATRICK JOSEPH, Office Electrician, Western Union Telegraph Co., Cable Station, Bay Roberts, Newfoundland.
OPARIN, BASIL JOHN, Electrical Draftsman, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.
ORLEY, GEZA ELEMER, Designer, Stone & Webster, Inc., 147 Milk St., Boston, Mass.
ORSINI, SANTIAGO, Inspecting Engineer, Municipal Public Works Division, Dept. of Interior, San Sebastian, P. R.
OTTONELLO, ROBERTO J., Works Engineer, Ottonello-Tibaldi & Co., Rincon 452, Buenos Aires, Argentina Republic, S. A.
PADBIDRI, NARSINGRAO S., Electrical Engineer, Cromptons Bombay, Ltd., 35-37 Apollo St., Fort Bombay, India
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PANATZER, A. L., Chief Electrical Engineer, Ohio Salt Co., Rittman; res., Akron, Ohio.
PATTERSON, C. A., District Foreman, Western Colorado Power Co., Durango, Colo.
PEDRAZZI, JUAN, Supt. of Substations, Mexican Light & Power Co., 2 a de Gante No. 20, Mexico, D. F., Mex.
PLAZA, HERNAN PALMA, First Electrical Inspector, Chilean State Railways, Calle Viana No. 611, Vina del Mar, Chile, S. A.
PRESTON, LESLIE H., Journeyman Wireman, Portland Railway, Light & Power Co., Hawthorne Bldg., Portland, Ore.
RAY, JOHN A., Electrician, Portland Railway Light & Power Co., Hawthorne Bldg., Portland, Ore.
REEVES, FRANK MAROME, Power Electrical Engineer, Western Electric Co., Inc., Hawthorne Works, Chicago, Ill.
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ROSIER, JOHN PAUL, Chief Electrician, Hudson Coal Co., Wolf Summit; res., Clarksburg, W. Va.
*ROSS, MALCOLM D., Engineer, Design Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.
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SLACK, WILLIAM S., Electrical Engineer International Machinery Co., Antofogasta, Chile, S. A.
SMITH, WILLIAM ROY, Tester, Installation Branch, Western Electric Co., Inc., Hawthorne; res., Chicago, Ill.
SREDENSCHEK, WILLIAM A., Student Engineer, Testing Dept., General Electric Co., Schenectady, N. Y.
STERTMAN, EDWARD JOHN, Chief Electrician, Imperial Oil Refineries, Ltd., Montreal, Que., Can.
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THORP, LAWRENCE J., Electrical Engineer, Western Electric Co., Inc., Chicago, Ill.
THVEDT, CHRISTIAN BERNHARD MARTIN, Asst. to Superintendent of Constr. Dept., United Electric Light & Power Co., 130 E. 15th St., New York; res., Brooklyn, N. Y.
ULBRICH, MAX ALFRED, Jr., Power Engineer, New York & Queens Electric Light & Power Co., Bridge Plaza, Long Island City; res., Rockaway Park, N. Y.
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WALKER, ESCHOL LECESTER, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.
WALKER, GEORGE EMERSON, Shift Charge Engineer, North Metropolitan Electric Power Supply Co., Willesden, N. W., 10, London, Eng.
WAYTS, MARTIN ELMAR, Plant Engineer, International Rubber Co., Anderson, Ind.
WEINREB, OSCAR, Electrical Engr., Acme-International X-Ray Corp., 341 W. Chicago Ave., Chicago, Ill.
*WHEELER, WILLIAM C., Statistical Engineer, Railway Motor Engg. Dept., General Electric Co., Schenectady, N. Y.
*WINJE, SEVERT WILLIAM, Engineer, Lt. & Pr. Dept., Indiana Service Corp., 122 East Wayne St., Fort Wayne, Ind.
WINKLEY, ERASTIS E., Electrical Engineer, E. E. Winkley & Co., 103 Euclid Ave., Lynn, Mass.
WRIGHT, JOHN LAWRENCE, Assistant, Transmission Dept., Pennsylvania Power & Light Co., Hazelton, Pa.
WYATT, HERBERT ERNEST, Telegraph Station Electrician, Western Union Telegraph Co., Hearts Content, Trinity Bay, Newfoundland.
*ZIMMERER, CECIL WALKER, Tester, Crocker-Wheeler Co., Ampere, N. J.; res., Brooklyn, N. Y.

Total 158.

*Formerly Enrolled Students.

ASSOCIATES REELECTED OCTOBER 26, 1923

HEILBRUN, RICHARD LUDWIG, Head of Firm, Dr. Richard Heilbrun, Berlin-Nowawes, Germany; for mail, New York, N. Y.
STRICKLER, WILL M., Designing Electrical Engineer, with Albert Kahn, 1000 Marquette Bldg., Detroit, Mich.
VIPOND, JAMES ELGIN, Draftsman, Kerry & Chace, Confederation Life Bldg., Toronto, Ont., Can.

MEMBER REELECTED OCTOBER 26, 1923

SPECHT, HANS CHRISTIAN, Designing Electrical Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

MEMBERS ELECTED OCTOBER 26, 1923

CALLAWAY, CLARENCE ROBERT, Vice-President and Chief Engineer, Gurney Elevator Co., 300 Eighth Ave., New York, N. Y.

HEATH, LESLIE O., Sales Dept., Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.

MAILLARD, ALBERT LUDOVIC, Electrical Engineer, Fuller & Maitland, 600 Walnut St., Kansas City, Mo.

PEARCE, JAMES GEORGE, Research Engineer, Metropolitan-Vickers Electrical Co., Ltd., Trafford Park, Manchester, Eng.

TRANSFERRED TO GRADE OF FELLOW OCTOBER 26, 1923

FULLER, LEONARD F., Radio Engineering Dept., General Electric Co., Schenectady, N. Y.

LANGLEY, GORDON R., Switchboard Dept. Canadian General Electric Co., Peterboro, Ont., Can.

TRANSFERRED TO GRADE OF MEMBER OCTOBER 26, 1923

HELLENTHAL, JOSEPH, Supt. of Transmission, Puget Sound Power & Light Co., Seattle, Wash.

KRANZ, HERMANN E., Development Engineer, Western Electric Co., Inc., Hawthorne Station, Chicago, Ill.

MELVIN, H. L., Electrical Engineer, Washington Water Power Co., Spokane, Wash.

MILNOR, JOSEPH W., Research Engineer, Western Union Telegraph Co., New York, N. Y.

MONTGOMERY, THEODORE D., Eastern District Manager, Cutler-Hammer Mfg. Co., New York, N. Y.

SHACKLETON, S. P., Engineer, American Telephone & Telegraph Co., New York, N. Y.

TIKHONOVITCH, BENEDICT, Electrical Engineer, Engineering Dept., New York Edison Co., New York, N. Y.

YENSEN, TRYGVE D., Research Engineer, Westinghouse Research Laboratory, W. E. & M. Co., East Pittsburgh, Pa.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held October 22, 1923, recommended the following members of the Institute for transfer to the grades of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

PETERS, JOHN FINDLEY, Technical Assistant Transformer Engineering Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

To Grade of Member

ALEXANDER, PETER P., Research Engineer, Thomson Research Laboratory, General Electric Co., West Lynn, Mass.

BECKETT, B. B., Consulting Electrical Engineer, San Francisco, Calif.

CANAVACIOL, FRANK E., Instructor. Department of Electrical Engineering, Polytechnic Institute, Brooklyn, N. Y.

CURTIS, MARSTON, General Electric Co., Duluth, Minn.

GARMAN, HARRY O., Consulting Engineer, Indianapolis, Ind.

HALE, GEORGE R., Electrical Engineer, Canada Carbide Co., Shawinigan Falls, Quebec

HARWOOD, PAISLEY B., Electrical Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

LEWIS, JOSEPH FRAZIER, Assistant to Manager, Pringle Electrical Mfg. Co., Philadelphia, Pa.

MEYER, HERBERT W., Statistical Engineer, Northern States Power Co., Minneapolis, Minn.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary, before October 31, 1923.

Aburto, V., Mexican Light & Power Co., El Oro, Mexico

Aguilar, J., Mexican Light & Power Co., El Oro, Mexico

Allen, R. W., Narragansett Electric Lighting Co., Providence, R. I.

Anzini, D. I., General Electric Co., Schenectady, N. Y.

Bates, S. P., General Electric Co., Pittsfield, Mass.

Beall, I. V., U. S. S. Coast Guard, "U. S. S. Morrill," Detroit, Mich.

Bell, St. J. E., General Electric Co., Schenectady, N. Y.

Bider, B., Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Bofinger, P. R., Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Boicourt, E. H., Iowa Light & Power Co., Rockwell City, Iowa

Brunnock, D. J., Brooklyn Edison Co., Brooklyn, N. Y.

Buckley, A. F., res., 111 W. 188th St., New York, N. Y.

Buell, W. G., Bureau of Pr. & Lt., City of Los Angeles, San Pedro, Calif.

Byl, D. H., General Electric Co., Schenectady, N. Y.

Cabot, G. E., Partner, Cabot, Cabot & Forbes, Boston, Mass.

Cantrall, O. L., General Electric Co., Atlanta, Ga.

Carr, H. F., General Electric Co., Schenectady, N. Y.

Casper, R. M., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Chevallier-Rufigny, J., International General Electric Co., Schenectady, N. Y.

Churchill, C. F., with Wm. C. Olsen, Kingston, N. C.

Clevenstine, G. G., Electric Power Equipment Corp., Philadelphia, Pa.

Cole, M. T., Dwight P. Robinson & Co., Inc., New York, N. Y.

Dormont, J., General Electric Co., Pittsfield, Mass.

Dyson, W., Georgia School of Technology, Atlanta, Ga.

Eccardt, M., Jr., Polar Wave Ice & Fuel Co., St. Louis, Mo.

Elliott, P., General Electric Co., Pittsfield, Mass.

Ellis, B. O., (Member), Construction Engineer New York, N. Y.

Farr, A. E., Waitsfield & Fayston Telephone Co., Waitsfield, Vt.

Farrand, Van D., Western Union Tel. Co., Salt Lake City, Utah

Flinchbaugh, L. D., New York State Railways, Rochester, N. Y.

Fuchs, W., A. B. See Elevator Co., New York, N. Y.

George, H. F., Consumers Power Co., Jackson Mich.

Gracey, A. F., Bell Telephone Co. of Pa., Philadelphia, Pa.

Hale, R. O., Westinghouse Elec. & Mfg. Co., Wilkes-Barre, Pa.

Hart, H., S. & H. Electrical Works, Chicago, Ill.

Haywood, W. E., American Tel. & Tel. Co., St. Louis, Mo.

Hellwig, E. C., res., 1229 Champa St., Denver, Colo.

Herrick, P. B., Electric Meter Engineering Co., Milwaukee, Wis.

Hill, H. O., Riter-Conley Co., Pittsburgh, Pa.

Hinzman, H. A., Elec. Supt., Harry A. Hanft, New York, N. Y.

Hobart, J. E., McClellan & Junkersfeld, Inc., E. St. Louis, Ill.

Hoppe, E. A., General Electric Co., Schenectady, N. Y.

Hubbard, H. S., General Electric Co., Pittsfield, Mass.

Huxford, J. H., Jr., General Electric Co., Schenectady, N. Y.

Jackson, F. W., American Appraisal Co., Milwaukee, Wis.

Jacobs, L.; res., 1130 Union Ave., New York, N. Y.

Jones, E. W., (Member), Kansas State Teachers College, Pittsburgh, Kansas

Kirkwood, R. F., General Electric Co., Pittsfield, Mass.

Knoderer, C. L., American Tel. & Tel. Co., Philadelphia, Pa.

Keetzle, J. J., Westinghouse Elec. & Mfg. Co., Huntington, W. Va.

Larabee, A. E., (Member), Major, Signal Corps. U. S. A., Washington, D. C.

Leavitt, H. J., Montpelier High School, Montpelier, Vt.

Lennox, T. C., General Electric Co., Pittsfield, Mass.

Littlewood, H. S., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Longbottom, C. M., Westinghouse Elec. & Mfg. Co., Pittsburgh, Pa.

Mackay, G. M. J., General Electric Co., Schenectady, N. Y.

Marshall, L. R., Southern Canada Power Co., Montreal, Que.

McDonell, F. W., New York Edison Co., New York, N. Y.

McGlone, J., American Tel. & Tel. Co., New York, N. Y.

McKee, P. B., California Oregon Power Co., Medford, Ore.

McLaughlin, E. F., (Member), General Electric Co., Atlanta, Ga.

Molinet, E., Cuban American Sugar Co., Oriente, Cuba

Moxley, W. F., (Member), Glen Alden Coal Co., Scranton, Pa.

Muffley, R. U., (Member), Washington Coast Utilities, Seattle, Wash.

Nakashima, T., Hamamatsu Tech. College, Hamamatsu, Japan, New York, N. Y.

Nemkowski, Boruch M., Westinghouse Elec. & Mfg. Co., Newark, N. J.

Nolte, F. W., West Penn Power Co., Weirton, W. Va.

Ost, P. J., (Member), Asst. City Engineer, San Francisco, Calif.

Owsley, J. H., Puget Sound Power & Light Co., Seattle, Wash.

Parry, R. E. R., General Electric Co., Schenectady, N.Y.

Pawson, P. N., Bradford Dyeing Ass'n., Bradford, R. I.

Peterson, F. W., Westinghouse Elec. & Mfg. Co., New York, N. Y.

Pflieger, J. A., Philadelphia Electric Co., Philadelphia, Pa.

Pierce, R. T., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Pierson, W. M., Adirondack Power & Light Corp., Schenectady, N. Y.

Pik, J., c/o Czechoslovak General Consulate, New York, N. Y.

Pliego, M., Mexican Light & Power Co., El Oro, Mexico

Pulsford, J. A., Public Service Electric Co., Newark, N. J.

Putman, H. V., Ideal Electric & Mfg. Co., Mansfield, Ohio

Randolph, A. F., (Member), Public Service Production Co., Newark, N. J.

Randolph, R. E., Staten Island Shipbuilding Co., Mariners' Harbor, N. Y.

Reznicek, J., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Reyskey, J. P., Allis-Chalmers Mfg., W. Allis, Wis.

Roser, J. O. L., General Electric Co., Pittsfield, Mass.
Rouse, G. H., General Electric Co., Pittsfield, Mass.
Rudd, W. C., (Member), with Geo. W. Hubley, Louisville, Ky.
Schouw, E. J., Allis-Chalmers Mfg. Co., W. Allis, Wis.
Schultz, A. S., Western Electric Co., Inc., Philadelphia, Pa.
Shaw, A. E., Jr., Electrical Engineer, Brooklyn, N. Y.
Shepherd, H. E., John B. Stetson University, De Land, Fla.
Shive, E. H., Philadelphia Electric Co., Philadelphia, Pa.
Slaughter, N. H., (Member), Western Electric Co., New York, N. Y.
Smart, H. J., General Electric Co., Pittsfield, Mass.
Snyder, L. G., Consumers Power Co., Jackson, Mich.
Steinbach, H. L., Westinghouse Elec. & Mfg. Co., Cleveland, Ohio
Stewart, S. F., Mass. Institute of Technology, Boston, Mass.
Straus, F. N., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Tallman, J. J., Union Lumber Co., Ft. Bragg, Calif.
Walker, H. R., Olds Motor Works, Lansing, Mich.
Walter, C. F., Northern Ohio Traction & Light Co., Kenmore, Ohio
Webster, J. S., Puget Sound Power & Light Co., Seattle, Wash.
Whitner, J., South-Eastern Underwriters Association, Atlanta, Ga.
Wickel, F. A., M. S. "Missourian," A. H. S. S. Co., San Francisco, Calif.
Wiggen, E. C., Portland Railway, Light & Power Co., Portland, Ore.
Woods, J. C., Commonwealth Edison Co., Chicago, Ill.
Wormull, S. J., Siemens Bros. & Co., Ltd., Winnipeg, Canada
Total 106.

Foreign

Connolly, W. H., State Electricity Comm. of Victoria, Melbourne, Aus.
Gerhart, J. J., Braden Copper Co., Rancagua, Chile, S. A.
Grente, F., Energia Electrica de Cataluna, Barcelona, Spain
Kennedy, P., State Engineer, Postmaster General's Dept., Perth, W. Australia
Okey, J. N. L., Woof & Salvesen, Christchurch, N. Z.
Perkins, H. W., Australian General Electric Co., Melbourne, Aus.
Thom, C. E., Vacuum Oil Co., Pty., Ltd., Melbourne, Victoria, Aus.
Weddell, J. A., Braden Copper Co., Rancagua, Chile, S. A.
Total 8.

STUDENTS ENROLLED OCTOBER 26, 1923

17381 Smith, Ray L., Kansas State Agri. College
17382 Bacon, Robert E., Northeastern Univ.
17383 Field, Howard M., Syracuse University
17384 Crockett, Elton G., Northeastern Univ.
17385 Soreff, Joseph, Mass. Inst. of Tech.
17386 Clark, Raymond E., Univ. of Kentucky
17387 Byers, John E., University of Kentucky
17388 Loftus, John B., Univ. of Kentucky
17389 Layman, James H., Univ. of Kentucky
17390 Ginocchio, Charles V., Univ. of Kentucky
17391 Scott, Clarence E., Univ. of Kentucky
17392 Russell, James R., Univ. of Kentucky
17393 Stoesser, Raymond A., Univ. of Kentucky
17394 Taylot, I. Forrest, Univ. of Kentucky
17395 Wile, Daniel D., University of Kentucky
17396 Payntz, William L., Univ. of Kentucky
17397 Barnett, Nugent M., Univ. of Kentucky
17398 Page, G. R., Univ. of Kentucky
17399 Ramsey, Dell M., Univ. of Kentucky
17400 Mustafa, Syed, University of Illinois
17401 Haines, Alvin B., Kansas State Agri. Coll.
17402 Mears, Roy H., Kansas State Agri. Coll.
17403 Weeks, Everett J., Kansas State Agri. Coll.
17404 Plank, George A., Kansas State Agri. Coll.
17405 Scott, Walter F., Rutgers College
17406 Cromley, Harry, Rutgers College
17407 Hobart, George A., Rutgers College
17408 Chappell, Matthew, Rhode Island State College
17409 Barker, Edward H., Northeastern Univ.
17410 McKimens, George J., Kansas State Agri. Coll.
17411 Cabacungan, Esteban A., Kansas State Agri. Coll.
17412 Wichman, Edward W., Kansas State Agri. Coll.
17413 Hybskmann, Vance L., Kansas State Agri. Coll.
17414 Rehberg, Alex F., Kansas State Agri. Coll.
17415 Swales, James K., Kansas State Agri. Coll.
17416 Schiffmayer, Francis, Rutgers College
17417 Ehrke, Louis F., Stevens Inst. of Tech.
17418 Eggenberger, John B., Stevens Inst. of Tech.
17419 Sanial, Arthur J., University of Illinois
17420 Hull, Randolph M., Northeastern Univ.
17421 Davis, George P., Mass. Inst. of Tech.
17422 Heim, John W., Pennsylvania State Coll.
17423 Fitzburgh, William J., Stevens Inst. of Technology
17424 Koeble, Emmett H., Marquette University
17425 Stodola, Frank, Marquette University
17426 Lee, Leung Y., Marquette University
17427 Wareing, Herbert F., Marquette Univ.
17428 Legler, Clarence H., Marquette Univ.
17429 Smith, Marcellus J., Marquette Univ.
17430 Mockus, Joseph J., Marquette Univ.
17431 Dennett, Hugh F., Marquette University
17432 Van Den Wymelenberg, Clement, Marquette University
17433 Holback, Ralph H., Marquette University
17434 Petranek, James J., Marquette University
17435 Curry, Thomas T., Marquette University
17436 Weidenbach, Glen O., Kansas State Agricultural College
17437 McIlvain, Randall B., Kansas State Agricultural College
17438 Boroff, Roy E., Kansas State Agri. Coll.
17439 Carter, Sherman H., Kansas State Agricultural College
17440 McKibben, Wayne E., Kansas State Agricultural College
17441 Engeset, E. D., Marquette University
17442 Patience, A. Melbourne, Toronto Univ.
17443 Griebling, Edward W., Rutgers College
17444 Bevan, James E., Lehigh University
17445 Seeman, Frederick C., Jr., Lehigh Univ.
17446 Holzshu, Charles D., Lehigh University
17447 Grieb, Conrad K., Lehigh University
17448 Allen, Walter R., Lehigh University
17449 Ratajczak, F. X., Lehigh University
17450 Keller, Francis R., Lehigh University
17451 Leavens, William B., Jr., Lehigh University
17452 Brown, Ernest E., Lehigh University
17453 Binkley, Edward L., Lehigh University
17454 Berger, Francis J., Lehigh University
17455 Winster, Luther C., Lehigh University
17456 Ayres, Clarence C., Jr., Lehigh University
17457 Krazinski, Leo C., Lehigh University
17458 Pineda U., Luis G., Lehigh University
17459 Beck, Frederick C., Lehigh University
17460 O'Brien, William C., Lehigh University
17461 Parker, Norman D., Jr., Lehigh University
17462 Curtis, E. A., Lehigh University
17463 Fister, Lee H., Lehigh University
17464 Wolcott, Leslie C., Lehigh University
17465 Bokum, William H., Lehigh University
17466 Rorabaugh, Merrill S., Lehigh University
17467 Paone, Anthony, Iowa State College
17468 Paxton, Ralph E., Iowa State College
17469 Horner, Arthur R., University of Penn.
17470 Dean, Joseph M., University of Iowa
17471 Johnson, George C., University of Iowa
17472 Heimbach, Arthur E., Penn. State Coll.
17473 Wing, Orlando H., University of Wisconsin
17474 Brown, Frederick C., University of Maine
17475 Carman, Willard A., Northeastern Univ.
17476 Schwab, William N., Univ. of Kentucky
17477 Helburn, L. B., University of Kentucky
17478 Spilman, Charles M., Univ. of Kentucky
17479 Smith, Robert R., University of Kentucky
17480 Gray, John L., University of Kentucky
17481 Lewis, Alex D., University of Kentucky
17482 Biosca, Louis F., Syracuse University
17483 Bowman, Curtis F., Syracuse University
17484 Chalupa, Paul B., Syracuse University
17485 Filsinger, Elmer H., Syracuse University
17486 Hall, Henry J., Syracuse University
17487 Langworthy, Reuben S., Syracuse Univ.
17488 Prosser, Raymond A., Syracuse University
17489 Woese, Carl Frank, Syracuse University
17490 Savage, J. Kenneth, Syracuse University
17491 MacDonald, William R., Jr., University of Maine
17492 Maurette, Rene G., Northeastern Univ.
17493 Jones, Albert E., University of Maine
17494 Ong, Benedict C., Univ. of Notre Dame
17495 Reilly, Austin V., Univ. of Notre Dame
17496 Heywood, Anderson H., Northeastern University
17497 Klingeschmitt, H. C., University of North Carolina
17498 Dunn, Warren S., Rutgers College
17499 Seibut, George, Rutgers College
17500 Brule, McLeah A., Univ. of Notre Dame
17501 Harker, Donald C., Mass. Inst. of Tech.
17502 Long, Edward H., Mass. Inst. of Tech.
17503 Peters, Jacob C., Jr., Penn. State College
17504 Stoker, Elmer F., Ohio Northern Univ.
17505 Hranac, Frank V., Univ. of Nebraska
17506 Haines, John E., University of Nebraska
17507 Edgerton, Harold E., Univ. of Nebraska
17508 Mace, Emory M., Univ. of Nebraska
17509 Funk, Paul V., Ohio Northern University
17510 Yerigan, Marion C., Ohio Northern Univ.
17511 Fulks, James K., Ohio Northern Univ.
17512 Stumpf, Frank C., Ohio Northern Univ.
17513 Ring, Joseph M., Ohio Northern Univ.
17514 Fresen, Martin H., Ohio Northern Univ.
17515 Woolever, Alfred E., Ohio Northern Univ.
17516 Chittick, Kenneth A., Rutgers College
17517 Thompson, George E., Mass. Inst. of Tech.
17518 Wild, Earle, Mass. Inst. of Tech.
17519 Brown, Leland P., Univ. of North Carolina
17520 Coffin, David D., Harvard University
17521 Packard, Mansfield M., Univ. of Maine
17522 Irish, Clifford V., University of Maine
17523 Brewster, Meredith W., Mass. Institute of Technology
17524 Stolte, Albert M., Mass. Inst. of Tech.
17525 Lyons, George W., Univ. of Illinois
17526 Krueger, David E., Univ. of Illinois
17527 West, Harold, Mass. Inst. of Tech.
17528 Finch, Carl V., Montana State College
17529 Cowan, Jack A., Montana State College
17530 Thomas, Everett J., Univ. of Wisconsin
17531 Turner, Elmer A., Northeastern Univ.
17532 Morley, Frank W., Northeastern Univ.
17533 Donker, Donald M., Univ. of Michigan
17534 Fenton, Almon N., Univ. of Michigan
17535 Johnson, Walter C., Univ. of Michigan
17536 Poole, Merlin L., Univ. of Michigan
17537 Starr, Leo R., University of Michigan
17538 Wolff, Leo, University of Michigan
17539 Vielmett, Clarence A., Univ. of Michigan
17540 Stephens, Orville W., Univ. of Michigan
17541 Sifritt, Kenneth McK., Univ. of Michigan
17542 Stirton, William E., Univ. of Michigan
17543 Robertson, Burtis L., Univ. of Michigan
17544 Osmun, Howard M., Univ. of Michigan
17545 Latson, Merle D., Univ. of Michigan
17546 Kooyoomjan, Martin C., Univ. of Mich.
17547 Jones, Ralph W., Univ. of Michigan
17548 Dorff, Louis A., Univ. of Michigan
17549 Case, Harlow M., Univ. of Michigan
17550 Bonninghausen, Hugo, Univ. of Michigan
17551 Burrows, Charles R., Univ. of Michigan
17552 Brown, Lewis M., Univ. of Michigan
17553 Davidson, Robert C., Yale University
17554 Downing, William C., Yale University
17555 Hofmann, Frederick, Yale University
17556 Hutchcraft, A. Stephens, Yale University
17557 Mermin, John, Yale University
17558 Newberg, Carl W., Yale University

17559 Randall, Henry, Yale University
17560 Skinner, Orville B., Yale University
17561 Spring, Ernest W., Yale University
17562 Wilcox, Harry A., Jr., Yale University
17563 Baker, Albert S., Yale University
17564 Brosler, Edward, Yale University
17565 Caldwell, Samuel P., Yale University
17566 Cureton, Thomas K., Jr., Yale University
17567 Wynne, Walter M., Yale University
17568 Rowe, Stuart B., Yale University
17569 Biach, John L., Yale University
17570 Wheeler, William R., Mass. Inst. of Tech.
17571 McClure, Robert B., Purdue University
17572 Harrell, Frederick E., Purdue University
17573 Brown, P. F., Purdue University
17574 Lentz, Samuel S., Purdue University
17575 Brion, A. A., Purdue University
17576 Davis, John M., Purdue University
17577 Sudranski, Lester L., Purdue University
17578 Willis, French H., Purdue University
17579 Mills, Simpson B., Purdue University
17580 Schafer, Kenneth M., Purdue University
17581 Sese, E. J., Ohio Northern University
17582 Parucker, R. E., University of Wisconsin
17583 Schramm, Frederic B., Case School of Applied Science
17584 Schmidt, John H., Penn. State College
17585 Boyer, Glenn C., Montana State College
17586 Lou, Howard, University of Colorado
17587 Winters, Ralph N., Penn. State College
17588 Sinnett, Chester M., University of Maine
17589 Bushey, Dwight C., Kansas State Agricultural College
17590 Axtell, Harold B., Kansas State Agricultural College
17591 Phares, Clifford W., Kansas State Agricultural College
17592 Storer, Sheldon B., Kansas State Agricultural College
17593 Kuhlman, Elmer C., Kansas State Agricultural College
17594 Hill, Raymond M., Kansas State Agricultural College
17595 Schemm, Christian W., Kansas State Agricultural College
17596 Garratt, Willis E., Kansas State Agricultural College
17597 Bennett, Howard O., Kansas State Agricultural College
17598 Schutte, Leo H., Kansas State Agricultural College
17599 Arnold, Mark W., Kansas State Agricultural College
17600 Wege, Harry R., Kansas State Agricultural College
17601 Berry, Theodore M., Kansas State Agricultural College
17602 Wimer, Loyal V., Kansas State Agri. Coll.
17603 Cash, Arnold B., Kansas State Agri. Coll.
17604 Piepho, Edward E., Mass. Inst. of Tech.
17605 Swinehart, Allen L., Ohio Northern Univ.
17606 Schreiber, Frederick C., Penn. State Coll.
17607 Clarke, Albert H., Syracuse Univ.
17608 Feuchter, William M., Syracuse Univ.
17609 Greis, Winiford K., Syracuse Univ.
17610 Heisler, J. Roland, Syracuse University
17611 McKinley, Reid B., Syracuse University
17612 Puls, Roy F., Syracuse University
17613 Reed, Ray J., Syracuse University
17614 Roy, Jack, Syracuse University
17615 Ruch, Allen M., Syracuse University
17616 Schweinberger, Arthur A., Syracuse Univ.
17617 Winkworth, Kenneth M., Syracuse Univ.
17618 Clair, John A., Syracuse University
17619 Hadley, R. H., University of Colorado
17620 McCanne, W. Gerald, Jr., Univ. of Colo.
17621 Barth, Albert H., University of Colorado
17622 Hughes, Harold H., Univ. of Colorado
17623 Sutherland, Daniel J., Univ. of Colorado
17624 Hamilton, Julius G., Univ. of Colorado
17625 Sayler, Ernest V., Univ. of Colorado
17626 Wallis, Lynn B., Univ. of Colorado
17627 Miller, Orville V., Univ. of Colorado
17628 Roys, H. E., University of Colorado
17629 Ford, J. Alexander, Rutgers College
17630 Neary, John S., Jr., Rutgers College
17631 Hunkins, Harold R., Brooklyn Poly. Inst.
17632 Burns, Arthur F., Syracuse University
17633 Brown, Lloyd C., State Coll. of Washington
17634 Huston, Robert D., Univ. of Maine
17635 Driscoll, Merwyn R., Univ. of Maine
17636 Sargent, Harold D., Univ. of Maine
17637 Turner, Otto C., University of Maine
17638 Handy, John E., Mass. Inst. of Tech.
Total 258

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William McConahey
W. K. Vanderpoel
H. P. Charlesworth

Treasurer
George A. Hamilton

Secretary
F. L. Hutchinson

Honorary Secretary
Ralph W. Pope

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Charles le Maistre, 28 Victoria St., London, S. W., England
A. S. Garfield, 45 Bd. Beausejour, Paris 16 E, France
H. P. Gibbs, Tata Sons, Ltd., Navsari Building, Fort Bombay, India
Guido Semenza, 39 Via Monte Napoleone, Milan, Italy
Lawrence Birks, Public Works Department, Wellington, New Zealand
Axel F. Enstrom, 24 A Grefturegatan, Stockholm, Sweden
W. Elsdon-Dew, P. O. Box 4563, Johannesburg, Transvaal, Africa

A. I. E. E. COMMITTEES

(A list of the personnel of Institute committees may be found in the September issue of the Journal and will be published again in the January issue.)

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Finance, G. L. Knight
Meetings and Papers, L. W. W. Morrow
Publication, Donald McNicol
Coordination of Institute Activities, W. I. Slichter
Board of Examiners, H. H. Norris
Sections, A. W. Berresford
Student Branches, C. E. Magnusson
Membership, M. E. Skinner
Headquarters, E. B. Craft
Law, H. H. Barnes, Jr.
Public Policy, H. W. Buck
Code of Principles of Professional Conduct, John W. Lieb
Safety Codes, H. B. Gear
Standards, H. S. Osborne
Edison Medal, Edward D. Adams
Research, John B. Whitehead

SPECIAL COMMITTEES

Columbia University Scholarships, Francis Blossom
Award of Institute Prizes, L. W. W. Morrow

TECHNICAL COMMITTEES AND CHAIRMEN

Educational, W. E. Wickenden
Electrical Machinery, H. M. Hobart
Electrochemistry and Electrometallurgy, J. L. Yardley
Electrophysics, F. W. Peek, Jr.
Industrial and Domestic Power, H. D. James
Instruments and Measurement, G. A. Sawin
Iron and Steel Industry, F. B. Crosby
Lighting and Illumination, G. H. Stickney
Marine, G. A. Pierce
Mines, F. L. Stone
Power Stations, Nicholas Stahl
Protective Devices, H. R. Woodrow
Telegraphy and Telephony, O. B. Blackwell
Traction and Transportation, N. W. Storer
Transmission and Distribution, F. G. Baum

A. I. E. E. SECTIONS AND BRANCHES

A complete list of the 47 Sections and 70 Branches of the Institute, with the names of the chairmen and secretaries, may be found in the September issue of the Journal.

A. I. E. E. REPRESENTATION

(The Institute is represented on the following bodies; the names of the representatives may be found in the September issue of the Journal and will be published again in the January issue.)

Council of the American Association for the Advancement of Science
American Bureau of Welding
American Committee on Electrolysis
American Engineering Council of the Federated American Engineering Societies
American Engineering Standards Committee
Apparatus Makers and Users Committee
Board of Trustees, United Engineering Society
Charles A. Coffin Fellowship and Research Fund Committee
Engineering Foundation Board
International Engineering Congress, Philadelphia 1926, Board of Management
John Fritz Medal Board of Award
Library Board, United Engineering Society
National Fire Protection Association, Electrical Committee
National Fire Waste Council
National Research Council, Engineering Division
Society for the Promotion of Engineering Education, Board of Investigation and Coordination
U. S. National Committee of the International Illumination Commission
U. S. National Committee of the International Electrotechnical Commission
Commission of Washington Award

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Motors.—Bulletin 2014, 32 pp. Describes type "T" heavy duty motors for direct current. The Reliance Electric & Engineering Company, 1088 Ivanhoe Road, Cleveland, Ohio.

Motors.—Bulletin, 12 pp. Describes squirrel-cage induction polyphase motors. New price sheets of this type motor, effective October 1, 1923, are also available. Century Electric Company, 1827 Pine Street, St. Louis, Mo.

Diesel Engines.—Catalog 805, 32 pp. Describes Fulton Diesel engines, showing actual installations in the field and picturing each successive step in their erection. Fulton Iron Works Company, 1259 Delaware Avenue, St. Louis, Mo.

Electrodes.—Bulletin, 6 pp. Describes the Soderberg continuous self-baking electrode for use in stationary and tilting electric furnaces. Electric Furnace Construction Company, 1015 Chestnut Street, Philadelphia, Pa.

CO_2 Meter.—Catalog 30, 8 pp. Describes a new CO_2 meter which measures electrically the percentage of CO_2 in flue gas. The instrument works on the principle of the difference in thermal conductivity of various gases instead of on the principle of chemical analysis. The Brown Instrument Company, Wayne & Windrim Streets, Philadelphia, Pa.

Motors.—Bulletin 134, 4 pp. Describes the Fynn-Weichsel motor, a radically new type of constant-speed alternating-current motor, which it is claimed combines all the desirable characteristics of both the slip-ring induction motor and the synchronous motor, and yet possesses none of their most objectionable features. Wagner Electric Corporation, 6400 Plymouth Street, St Louis, Mo.

Tachometers, Recording and Indicating.—Bulletin 317, 32 pp. Two types of tachometer equipment are described in this bulletin, the pneumatic and electric. The recording tachometer provides reliable measurement and complete record of speed, which is automatically traced on a paper chart. These records show actual speeds as they take place, together with time of occurrence. The Bristol Company, Waterbury, Conn.

Transformers.—Bulletin 2023, 4pp., describing pressed steel cases for distributing transformers. Bulletin 2026 is an interesting description of the method of transporting transformers to their destination in the Sierra Madre Mountains of Mexico, and illustrates some of the difficulties of delivering exported electrical equipment. Bulletin 2027 describes the installation of two 15,000 kv-a. polyphase transformers. Pittsburgh Transformer Company, Columbus & Preble Avenues, Pittsburgh, Pa.

NOTES OF THE INDUSTRY

Radio Transformer.—The Killark Electric Manufacturing Company, St. Louis, Mo., has placed on the market a new radio frequency amplifying transformer designed for use with a loop, and made in three different types for one, two or three stages of radio frequency amplification.

The Gibb Instrument Company, of Bay City, Michigan, manufacturers of electric welding equipment, has appointed H. A. Wilson manager of the Detroit branch, vice F. M. Luchs, resigned. Mr. Wilson was formerly district manager for A. P. Munning & Company, of New York.

The Production of Porcelain for Electrical Insulation.—A paper by Frank H. Riddle, Director of Research, Champion Porcelain Company, Detroit, Mich., which appeared in seven installments in the JOURNAL of the A. I. E. E., completed with the October issue, is available in reprint form, and copies will be sent to interested readers upon application to the Jeffery-Dewitt Insulator Company, 50 Church Street, New York.

Anti-Friction Bearings in the Steel Mills.—A paper 51 pp. by A. M. MacCutcheon, Chief Engineer, Reliance Electric & Engineering Company. Describes the use of ball and roller bearings in electrical machinery and the experiences of users and manufacturers. The paper was presented before the Association of Iron and Steel Electrical Engineers, and includes the discussion on the subject. Copies may be obtained from the Reliance Electric and Engineering Company, 1088 Ivanhoe Road, Cleveland, Ohio.

The Valley Electric Company, St. Louis, Mo., manufacturers of single-phase and polyphase ball bearing motors, rectifiers and other electrical products, has appointed E. W. Martin as Chicago District Manager. Mr. Martin was previously connected with the Westinghouse Electric and Manufacturing Company for a number of years in various capacities.

The appointment of C. L. Krentz in the sales department at the home office in St. Louis is also announced by the Valley Electric Company.

The Link Belt Company, Chicago, Ill., has announced the purchase of the Meese & Gottfried Company of San Francisco, Los Angeles, Seattle and Portland. The Meese & Gottfried Company, and its predecessors, have been manufacturers of power transmission machinery and distributors of conveying and transmission machinery on the Coast for more than forty years. It is the intention of the new owners to add to the facilities and enlarge present stocks so that prompter service to its customers will be insured. The new organization will be known as Link-Belt Meese & Gottfried Company, with headquarters at San Francisco. Charles Piez is Chairman of the Board of the new Company.

The Norma Company of America has placed contracts for the erection of the first unit of its new plant at Stamford, Conn. The property acquired consists of seventeen acres of land, and the buildings now under construction will be of one-story, saw-tooth roof type occupying about 60,000 square feet of space. The company's present plant at Anable Avenue, Long Island City, N. Y., will be continued for the production of Norma precision open type annular ball bearings. The Stamford plant will be equipped for the manufacture of Hoffman precision ball bearings, the American rights to which, as also to all other Hoffman products, were recently acquired by the company. The plant will also be equipped for the expansion of the manufacture of Norma precision ball bearings.

The Champion Switch Company, incorporated in Ohio, has been formed with the following officers: F. D. Stranahan, President; R. A. Stranahan, Vice-President; R. W. Lillie, Vice-President and Sales Manager; J. F. Sinclair, Treasurer and General Manager; W. W. Hoffman, Secretary and W. L. Stinson, General Superintendent. The company has taken under lease plants owned by the Ferguson Shipbuilding Company, 550 Abbot Road, Buffalo, N. Y., and will manufacture high and low tension switching equipment, consisting of disconnecting switches, bus supports, choke coils, etc. It has been difficult for manufacturers to obtain insulators suitably designed for use with this class of equipment. The Champion Switch Company enjoys an association with the Jeffery-DeWitt Insulator Company to the extent that porcelains have been especially designed to conform with the exacting standards determined by the advancement of substation and transmission lines. The method of attaching mechanical devices to the insulators is new and novel and creates a unit type design. Many improvements have been made in the design and operation of the switchgear itself. Standardization and interchangeability of parts has been one of the principal objectives in designing the apparatus.